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Gopher Tortoise Nest Detection at Camp Shelby, Mississippi

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ABSTRACT: Declining populations of the gopher tortoise (*Gopherus polyphemus*) have prompted management efforts including methods to increase egg clutch survival. Estimates are that as many as 88 percent of all clutches are being destroyed by predation. The most popular protection method has been to locate the clutch and protect it from predation with a metal cage or hardware screen. Locating the clutch without damaging or extensively disturbing the eggs requires highly skilled personnel, and traditional techniques for nest location appear to be unusable for populations in western areas where soils contain a higher clay fraction. The analysis reported here focused on the use of ground penetrating radar (GPR), multi-frequency frequency domain electromagnetism, shallow seismic reflection, electrical resistivity, magnetic field gradient, and thermal imaging for nest detection. Though all instrumentation methods have proven worth within their dedicated disciplines, none were truly successful at locating *G. polyphemus* clutches in the field in Southern Mississippi. GPR appeared the most viable, though the particular methods used could not be called successful in this trial. Thus, reliance on any of these techniques is not recommended for critical surveys intended to accurately locate tortoise nests and egg clutches.

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Preface

The research documented in this report was performed during the period May to June 2001 as part of the CNN-T011, Maneuver Disturbance Assessment for the Conservation Program, “Training Lands Management – Characterization, Analysis, and Mitigation,” under program element P622720, Army Environmental Quality Technology. This research was conducted under the direct supervision of Dr. Harold Balbach, U.S. Army Engineer Research and Development Center, Construction Engineering Research Laboratory (ERDC/CERL), in support of the Army Threatened and Endangered Species Research Program.

The research was conducted and compiled by Jay Bennett, Lewis Smithhart, Janet Simms, Michael Hargrave, Tad Britt, and Don Pitts. Jay Bennett performed the analysis of the thermal imaging and electromagnetic data. Janet Simms performed the ground penetrating radar data analysis. The shallow seismic reflection analysis was performed by Lewis Smithhart, and electric resistivity and magnetic field gradiometry by Mike Hargrave and Tad Britt. Biological expertise on the gopher tortoise and logistical support were provided by Deborah Epperson and Colleen Heise of The Nature Conservancy Camp Shelby Field Office.

At the time of this report’s publication, the Commander and Executive Director of ERDC was COL James R. Rowan, EN, and the Director of ERDC was Dr. James R. Houston.

1 Introduction

Background

The gopher tortoise (*Gopherus polyphemus*) is a terrestrial reptile that was once quite plentiful throughout the Southeastern United States from North Carolina into Texas. However, due to factors such as habitat loss to agriculture and urbanization, and human and animal predation, their numbers have been in decline for the past several decades. In addition to population decline throughout its range, the tortoise has been extirpated from Texas and North Carolina, and has a limited, precarious existence in extreme southern South Carolina and extreme eastern Louisiana.

Declining populations of *G. polyphemus* have prompted management efforts including methods to increase egg clutch survival. Locating the clutch without damaging or extensively disturbing the eggs requires highly skilled personnel, and traditional techniques for nest location, developed in Florida, appear to be unusable for populations in western areas where soils contain a higher clay fraction. In addition, numerous research efforts require finding the clutches for measurement, count, fertility, and related data. The analysis reported here focused on the use of ground penetrating radar (GPR), multi-frequency frequency domain electromagnetic (FDEM), shallow seismic reflection (SSR), electrical resistivity (ER), magnetic field gradient, and thermal imaging (TI) for nest detection.

Species Description

The adult gopher tortoise is a medium sized land turtle, the only native tortoise in its range. While moderate geographical variations have been noted (Landers et al. 1982), the average size is accepted to be within the range of 9–11 inches (23–28 cm) in length, weighing 8–10 pounds, with extremes reported at 14 inches (36 cm) and 15 pounds (6.8 kg) (Dietlein and Franz 1979). They lack the webbed feet of an aquatic turtle, and have distinct submaxillary gular glands and an unhinged shell (Auffenburg 1978; Ernst and Barbour 1972). The tortoise's shell is domed and will vary by population in color from light tan to a darker gray. Description in the literature is rather abundant with little to no controversy.

G. polyphemus is the only tortoise both within its range and east of the Mississippi River. Three other tortoises in the genus *Gopherus* are found in North America: the Texas tortoise (*G. berlanderi*), the desert tortoise (*G. agassizii*) of the California, Arizona, and Nevada deserts, and the Bolson tortoise (*G. flavomarginatus*) of northern Mexico. All species are considered to be at risk at this time.

Distribution

As stated earlier, the species distribution has declined substantially from its original range. Now found, often sporadically, only from extreme southern South Carolina to far eastern Louisiana, its decline is quite similar and related to that of the red-cockaded woodpecker. Like the woodpecker, the tortoise was most often found in upland, open canopy woodlands of the longleaf pine ecosystem. These lands were characterized by open pine forest and plentiful ground cover vegetation that constitutes the tortoise's diet.

While a comprehensive list of military facilities with gopher tortoise populations has probably not been perfected, there have indeed been attempts. Wilson et al. (1997) listed 18 military installations with documented onsite *G. polyphemus* populations. In addition to Camp Shelby, MS, major populations of *G. polyphemus* exist on Camp Blanding, FL, Forts Benning and Stewart, GA, and Eglin Air Force Base, FL.

Habitat

A strong influence in this ecosystem is frequent wildfire, which controls midstory growth. The longleaf pine is markedly fire resistant, and ground cover recovers rapidly and is even enhanced by fire. A positive, linear relationship usually exists between herbaceous groundcover and tortoise population densities (Auffenburg and Iverson 1979), with areas of generous ground cover (80 percent) supporting up to 20 times more tortoises than areas of sparse ground cover. The open canopy is essential not only for ground cover growth and providing nutrition, but also to provide ground temperatures conducive to hatching the tortoise eggs (Landers et al. 1982).

The interactivity of ecosystem factors must be noted. Longleaf pines provide an open canopy, the fire suppresses the midstory that would otherwise suppress the ground cover, and the ground cover feeds the tortoise.

Several predictors have been attempted to characterize gopher tortoise habitat. Cox et al. (1987) provided a copious, comprehensive account of 32 vegetation communities supporting *G. polyphemus* in Georgia and Florida. Soil types were described by Auffenburg and Franz (1982), Lohoefer (1982), and Landers et al. (1982). These reports most importantly described sandy soils that allow rapid drainage and easy

digging, though they also alluded to some tortoise populations in clay soils, and others in shallow soils underlain by hardpan. Ruderal areas have also become increasingly important (Auffenburg and Franz 1982; Epperson and Heise 2001).

Legal Status

The western population of *G. polyphemus* is federally listed as Threatened. This population occurs in extreme southwestern Alabama (three counties), extreme eastern Louisiana (three parishes), and all of southern Mississippi. The other states with the tortoise share a Federal status of *species of concern* or, in the current usage, a *species at risk*.

State status of the tortoise varies. Mississippi and South Carolina both list the tortoise as Endangered; Louisiana and Georgia list it as Threatened. Florida has it as a *species of special concern*, while in Alabama it is a protected nongame species. To some degree, these listings parallel the state of local populations, with those having the smallest remaining numbers given the highest status.

Significantly, the species is decidedly in decline throughout its range and, if this trend is not reversed, more stringent listings can be expected. From experience following the listing of the red-cockaded woodpecker, it appears clear that Federal listing of the eastern tortoise populations has the potential to significantly impair Army mission uses at affected locations. Numerous Army-sponsored research projects, including the one reported here, seek to increase knowledge of tortoise needs and to improve management practices to ensure survival and sustainment of the species so as to preclude the need for more widespread Federal listing within its eastern populations.

Nesting

Declining populations of the gopher tortoise have prompted management efforts which in some cases have included methods to increase egg clutch survival. Estimates are that as many as 88 percent of all clutches are being destroyed by predation (see Cox et al. 1987 and references within). The most popular protection method has been to locate the clutch and protect it from predation with a metal cage or hardware screen. The clutch must be located without damaging or extensively disturbing the eggs.

Locating nests in situ provides information on reproductive parameters such as clutch size, nest placement, and a variety of other data. Finding these clutches is not necessarily easy, even though they are most often buried in the apron of the burrow (Landers et al. 1982). Butler and Hull (1996) reported 84 percent of clutches

in the apron (N=25). Landers et al. (1982) reported the same percentage (N=110) on or near the apron in Southwestern Georgia nest sites.

Clutch size is variable, with Landers et al. (1980) reporting 4–12 eggs with a mean and standard deviation of 7 and 1.7, respectively. Commonly, nests contain five ping-pong-ball sized eggs (40.5 mm–53.2 mm with a mean and standard deviation of 44.8 and 1.6 mm) buried 15–25 cm below the surface. Butler and Hull (1996) reported distances from the surface to the uppermost egg ranging from 6–18 cm, with a mean and standard deviation of 12.6 and 3.7 cm. Diameters ranged from 36.3–51.7 mm with a mean and standard deviation of 42.2 and 2.6 mm.

When located in predominantly sandy soils, the most common method is to carefully probe with a small wire. However, while the tortoise prefers sandy soils, it may also use loamy and even clay soils (Lohofener 1982). Those nests found in clay soils present significant difficulties in that probing is not successful and digging may damage the eggs. Instead, nests are located by manually inspecting aprons and by feeling around in the soil with one's hands. Both methods are labor intensive and time consuming, and some nests may be missed.

Approach

An attempt was made in June 2001 to locate gopher tortoise eggs using nonintrusive subsurface survey methods developed for archeology and other disciplines. The Camp Shelby study site was in Forrest and Perry counties in Mississippi. A majority of Camp Shelby's lands are within the DeSoto National Forest, used under a special use permit. The soils at Camp Shelby have a higher clay content than those typically found in the eastern portion of the gopher tortoise range and typically include: Benndale and Heidel soils, Eustis and Lakeland loamy sands, Heidel sandy loam, McLaurin and Benndale fine sandy loam, and Ruston and Lucedale soil.

Standard probing techniques were not suitable to these soils and drove the interest in non-intrusive methods for the detection of gopher tortoise nests. Noninvasive GPR, SSR, ER, and TI techniques were chosen to analyze because they cause no physical damage to the gopher tortoise eggs and nests.

Mode of Technology Transfer

The information included in this report is one portion of the materials prepared by the Engineer Research and Development Center (ERDC) to assist installation natural resources and TES program managers. The primary means of communicating

the tortoise behavior information will be through publication in the scientific literature, as well as through the availability of this report. The specific data presented are intended to be used in the preparation of biological opinions related to planned Army actions where the gopher tortoise is present. The data will also be used for endangered species management plans (ESMPs), integrated natural resources management plans (INRMPs), and in the preparation of ecological risk assessments involving training and other land disturbing activities where the tortoise is present.

This report will be made accessible through the World Wide Web (WWW) at URL:
<http://www.cecer.army.mil>

2 Methods

Overview

The techniques described here were selected from among a wide array of nonintrusive methods known to have value in fields of study where location of underground features is desired. Archeology is one such professional application for many of these techniques, and it was the known application of these systems in archeological surveys which led to the proposal that they might be useful for location of *G. polyphemus* nests and egg clutches.

Geophysical Methods

Frequency Domain Electromagnetic System

The equipment used in the analysis is a GEM-3 developed by Geophex., Ltd (Raleigh, NC). The GEM-3 is a multi-frequency FDEM system (Won 1997) (Geophex 1998). The collection of multi-frequency FDEM data allows for electromagnetic induction spectroscopy (EMIS) of targets and background materials (Won 1998). EMIS signatures characterize the objects' geometry and material composition and consist of complex in-phase and quadrature frequency responses. These EMIS signatures can provide a method to discriminate items of interest based on their geometry and material composition. The frequencies used during the analysis were 150, 510, 990, 2430, and 8370 hertz.

Ground Penetrating Radar

Ground penetrating radar is also an electromagnetic (EM) method like FDEM; however, it differs significantly from the induction EM method described above. At the lower frequencies (kilohertz range) where EM induction instruments operate, conduction currents (currents which flow via electrons in a metallic matrix or ions in solution) dominate and energy diffuses into the ground. At the higher frequencies (megahertz range) used by GPR, displacement currents (currents associated with charges that are constrained from moving any distance) dominate and EM energy propagates into the ground as a wave.

GPR is used to image the subsurface by transmitting an EM pulse into the earth and measuring the return signal. The frequencies used in GPR typically range from 10 to 1000 MHz. While in the earth, the EM signal undergoes refraction, reflection, scattering, and dispersion. Contrast in the dielectric permittivity at material boundaries causes the EM wave to be reflected and refracted. Soil conductivity is a major factor in determining if GPR can be used successfully at a site. High conductivity soils (e.g., with a high clay and moisture content) can significantly attenuate the EM signal, which frequently renders GPR virtually useless.

A Sensors & Software, Inc. (Mississauga, Ontario, Canada) Noggin system and pulseEKKO (PE)1000 system were used to collect the GPR data. The Noggin is noted for user-friendliness, simplicity, and its self-contained data acquisition system. Both the transmitter and receiver antennas are contained in one unit mounted on a cart that is pushed along the surface at a slow walking speed. A 250-MHz antenna was attached to the Noggin during the preliminary study at the Waterways Experiment Station (WES) site, Vicksburg, MS, but a 1000-MHz antenna was used at Camp Shelby. The PE1000 system allows the user more flexibility in survey design and data acquisition; however, it is more labor intensive and requires an experienced user. Three antenna frequencies (450, 900, and 1200 MHz) were evaluated during the preliminary study, but only the 1200-MHz antenna was used at Camp Shelby. For both studies, the GPR survey was performed in reflection mode with the antennas oriented perpendicular to the survey line. In reflection profiling, the transmitter and receiver antennas are kept a fixed distance apart and both antennas are simultaneously moved along the survey line. When using the Noggin system, a wheel odometer incorporated into the system was used to monitor the distance traveled and initiate data sampling at 1.25-cm increments. With the PE1000 system, data were collected at a user-specified sampling rate and distance was controlled by placing fiducial markers in the data at known distances. The time (in nanoseconds) required for the EM wave to travel through the subsurface and return to the receiver is recorded at each sample station. The GPR profile is constructed by plotting the received signal against two-way travel time at each sample station along the survey line.

Seismic Method

The SSR method is in the development stage and should not be confused with classical “Seismic Reflection,” which, although analogous, bears little practical resemblance. The concept is simple: Matched geophones placed in the test area receive signals from a nearby seismic source (or tapper). Received signals are compared for differences that indicate reflections from a subterranean anomaly (e.g., a nearby cluster of turtle eggs).

The theory supporting the use of SSR is as follows. In a limited area, seismic signals from the point source will show only minor frequency and amplitude deformation as they propagate across a homogenous field. If, however, the field contains anomalies, then reflections from these anomalies will combine algebraically with the primary source waves to create a resultant wave shape that is distinctly different from the source wave. Size, hardness, shape, and distance can affect the appearance of this composite waveform. The blue and red signals in Figure 1 combine to form the green waveform. This illustration shows how amplitude and arrival time combine to form the resultant waveform.

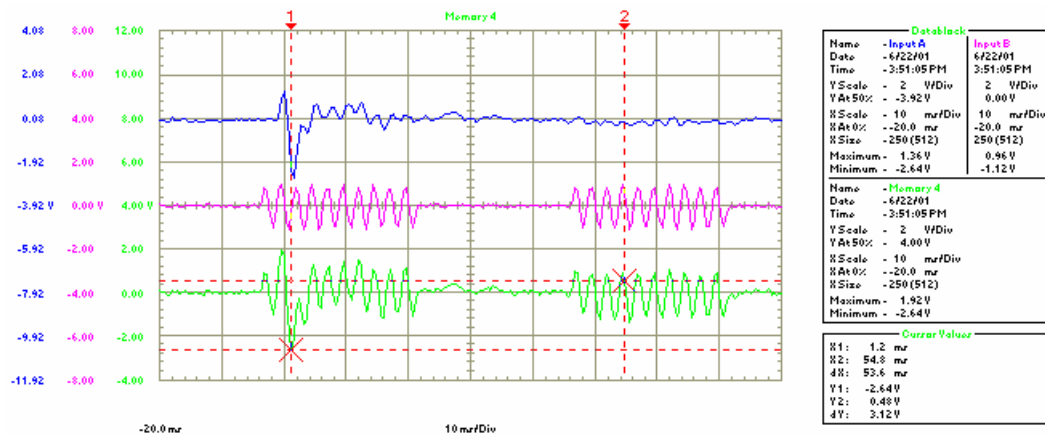


Figure 1. Seismic reflection example

SSR is collected with two matched Model L22 Geophones (Geospace Technologies, Houston, TX) with brass bases, a dual channel seismic amplifier set for a gain of 18 decibels (dB), a Model 97 Scopemeter (Fluke Corp., Everett, WA), a laptop computer (Dell Corp., Round Rock, TX) with FlukeView software, and a seismic source, consisting of an ERDC-fabricated, single-point electronically controlled vertical plunger. Figure 2 shows the dual channel seismic amplifier and the Fluke Scopemeter. Figure 3 shows the vertical plunger.

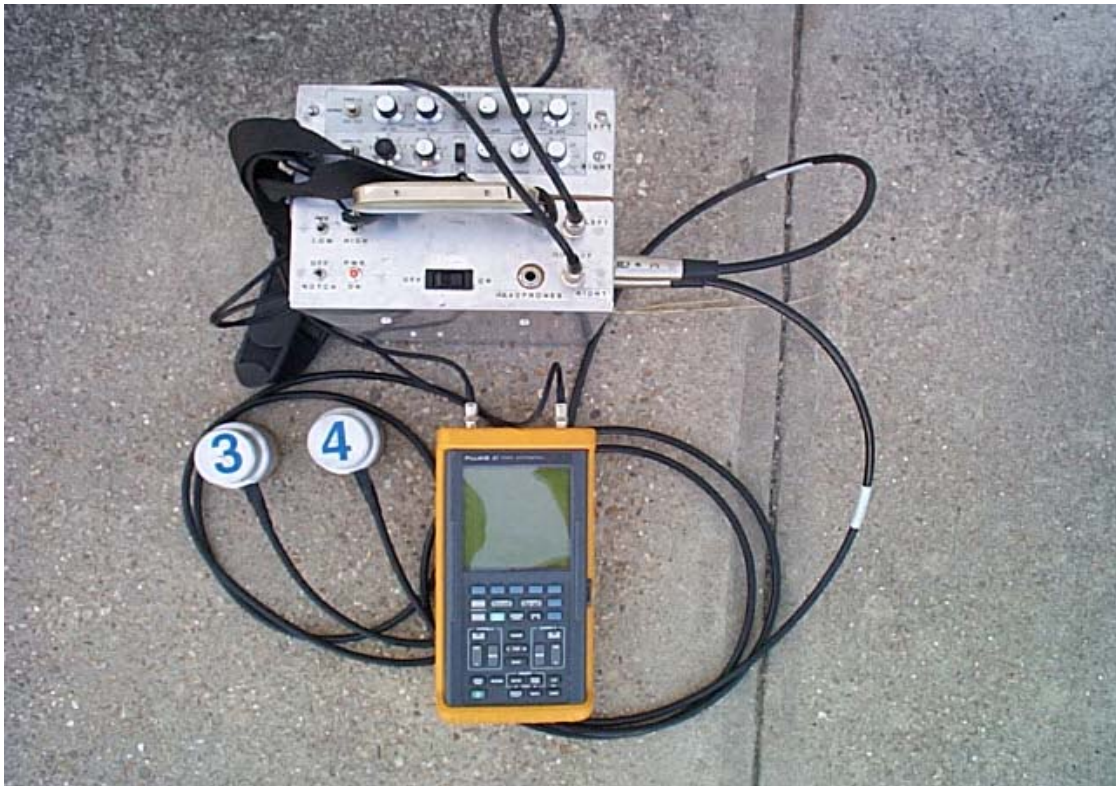


Figure 2. Dual channel seismic amplifier with Fluke Scopemeter.

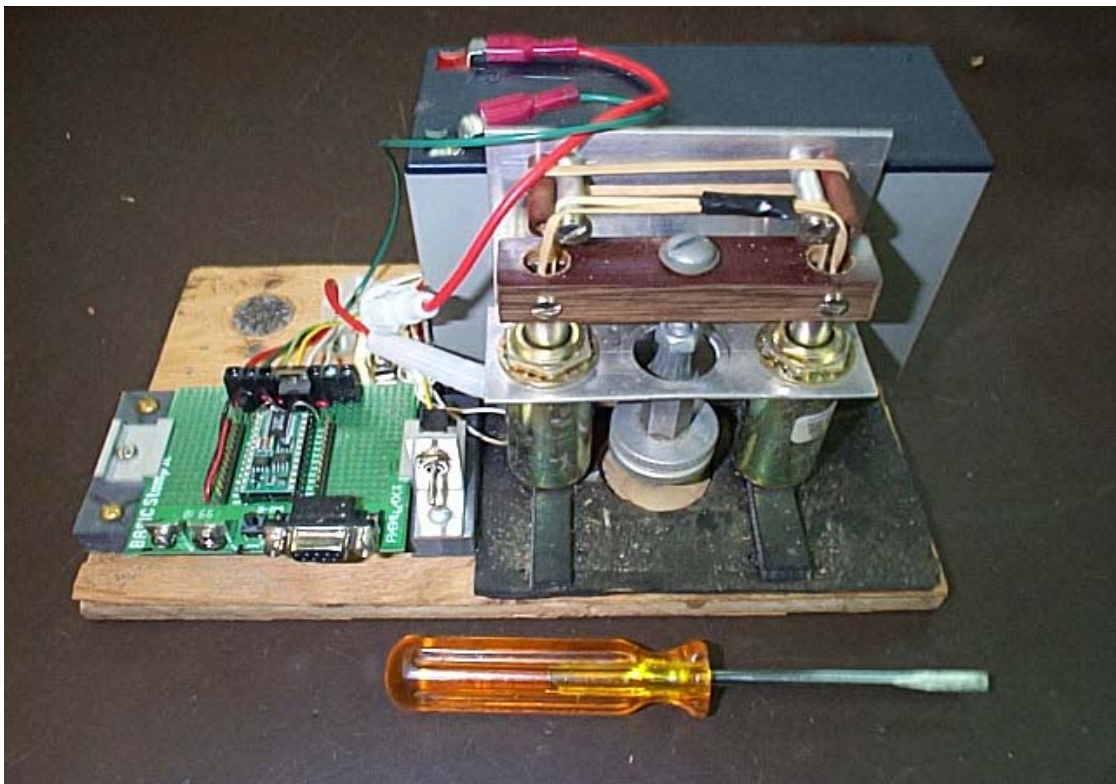


Figure 3. Electronically controlled vertical plunger.

Electrical Resistivity

Resistivity surveys (Bevan 1998; Heimmer and De Vore 1995; Scollar et al. 1990) introduce an electrical current into the ground and measure the ease or difficulty with which the current flows through the soil. The unit of measure is the ohm. Resistivity is governed by the number and mobility of free charge carriers (principally soluble ions). The simultaneous availability of soil moisture and soluble salts determines the free charge carrier concentration in the soil. The mobility of the soluble ions is governed by soil moisture content, soil grain size, temperature, soil compaction, and the surface chemistry of the soil grains. Archaeological features often have resistivity properties that differ from the surrounding soils. It is this contrast that creates the signal of interest in a resistivity survey (Somers and Hargrave 2001; Somers 1997:23).

The resistivity survey was conducted using a Geoscan Research (Bradford, West Yorkshire, England) RM-15 Resistance Meter equipped with an MPX15 Multiplexer and PA5 probe array. The frequency, current value, and integration time were adjusted to ensure that random defects in the survey associated with the instrument would be less than 1:2000. Grids were surveyed using a parallel twin configuration. That is, three probes were spaced at 0.5-m intervals. This resulted in the simultaneous collection of two side-by-side data values each time the probes were inserted into the ground. The electrode spacing of 0.5 m provided a survey response between roughly 0.20- and 1.0-m depth. Data were collected at 0.5-m intervals along the north-south transects, and transects were spaced at 1-m intervals east-west. The data sample density was four samples per m².

Magnetic Field Gradient

Magnetic field gradient surveys (Bevan 1998; Heimmer and De Vore 1995; Scollar et al. 1990) can be thought of as mapping deviations from uniformity in the earth's magnetic field that are caused by the presence of archaeological features and/or artifacts. The earth's magnetic field changes continuously through time and short-term changes are usually greater than the distortion associated with archaeological features. Temporal change must be removed from the survey data to reveal distortions associated with archaeological phenomena. Therefore, all archaeomagnetic surveys must be performed with two magnetic sensors (magnetometers). One magnetometer records the time-variable component, and the other records the spatial data and time-variable component. The latter component is removed from the survey data by subtraction. The Geoscan FM-36 used in this study includes two flux-gate sensors. Magnetic data are measured in nanoTeslas (i.e., one billionth of one Tesla) (Somers and Hargrave 2001; Somers 1997:23–24).

The archaeological record has two basic properties or mechanisms that distort the earth's magnetic field: remnant magnetization and magnetic susceptibility. Remnant magnetization is the familiar "permanent magnet" effect and is associated with iron and steel objects, ceramics, hearths, fire pits, and some fire-altered rocks and soils. In these materials, the remnant magnetization originates from heating iron oxides (found in most but not all soils) above a critical temperature (565–675 degrees Centigrade [°C]). When the soil cools, the temperature-induced changes in the iron oxide crystals become permanent. It is this change that generates a remnant magnetic field. This thermally created magnetic field adds vectorially to the earth's magnetic field to cause a local distortion. Thus, most cultural objects and processes associated with heating are potential archaeomagnetic survey objects of interest (Somers and Hargrave 2001; Somers 1997:23–24).

Magnetic susceptibility alters the earth's magnetic field directly in a manner roughly analogous to the way porosity alters the flow of water through a solid. Where magnetic susceptibility is large (high porosity) the magnetic field is increased, and where the magnetic susceptibility is low (low porosity) the magnetic field is decreased. Many cultural objects and processes (thermal, biochemical, physical, and mechanical) locally increase the magnetic susceptibility of the native soil. The mechanism for this increase also is associated with changes in the iron oxide crystal structures within the soils. Local changes in site magnetic susceptibility alter the earth's magnetic field, and it is this distortion that can be mapped. In magnetic surveys, remnant magnetization effects are usually somewhat greater than susceptibility effects (Somers and Hargrave 2001; Somers 1997:23–24).

A Geoscan Research FM-36 Fluxgate Gradiometer was used in the magnetic survey. It was operated in the 0.1-nT (most sensitive) range. Data sample density was 16 samples per m². Eight readings per meter were collected along the north-south transects, and transects were spaced at 0.5-m intervals east-west. Considerable care was taken to balance and align the instrument properly. The site is relatively quiet magnetically, and proper configuration of the instrument was easily achieved.

In each grid, data collection began in the southwest corner and proceeded along a series of N-S transects. Preliminary maps of each grid were inspected in the field to ensure that data quality was good and to provide a basis for decisions about the location of subsequent grids. The surveyed area was covered by low (recently mowed) grass, and survey conditions were excellent.

Thermal Imaging Method

The thermal imaging method is based on the assumption that thermal conductivity of the eggs and the soil surrounding them is different. This contrast would allow for a different rate of heat transfer from the surface to soil beneath the eggs, which would lead to a thermal difference on the soil surface above the nest. A Thermacam SC1000 (FLIR Systems, Inc., Portland, OR) was used in the analysis. The SC1000 has a 256 by 256 element focal plane array. The spectral range of the system is from 3.4–5.0 μm . The detector is Stirling cooled to 70 degrees Kelvin [$^{\circ}\text{K}$].

3 Preliminary Study

Test Grid

Before visiting tortoise colonies, researchers performed a preliminary study at the WES site to determine if any of the methods described above were feasible for detecting gopher tortoise nests. These tests were conducted in a test bed consisting of a sandy soil with some small pebbles. A 1-m wide and 2-m long grid was constructed as shown in Figure 4. Three mock tortoise nests were placed within the grid at a depth of 15 to 20 cm. Based on the gopher tortoise egg's mass and calcified shell (Linley and Mushinsky 1986), small size chicken eggs were used to simulate tortoise eggs. One nest contained four eggs, another (shown in Figure 5) held five eggs, and three eggs were placed in the third nest. Background surveys using a 20-cm survey line interval were performed with both geophysical survey methods and SSR both prior to and after nest emplacement.



Figure 4. Test grid with mock tortoise nests.



Figure 5. Mock tortoise nest.

Ground Penetrating Radar System

The preliminary testing confirmed that a minimum radar antenna frequency of 1000 MHz is required to detect any signature that may be related to a tortoise nest at the shallow depths involved. Figure 6 compares the background and nest profiles for the three survey lines where nests were emplaced. Difference between the pre- and post-nest profiles is notable, although sometimes subtle. The preliminary study did indicate, however, that it is potentially feasible to detect tortoise nests using GPR.

Frequency Domain Electromagnetic System

Figure 7 shows the multi-frequency FDEM system being used to collect data over the test grid. The background profile in Figure 8 was collected before the mock nest was placed at 0.55 m. The Day 1 profile was collected the same day the mock nest was placed at 0.55 m along the profile line. The Day 7 profile was collected 1 week later. One rainfall occurred during this week. As shown in Figure 8, a difference between the background profile and the nest profiles of the multi-frequency FDEM system is discernable. Without the background profile to compare against, however, the difference caused by the presence of the nest would be difficult to discern from other minor anomalies. The comparison is done with respect to the sum of the quadrature returns for the five frequencies. The in-phase returns did not show any significant change over the mock nest location.

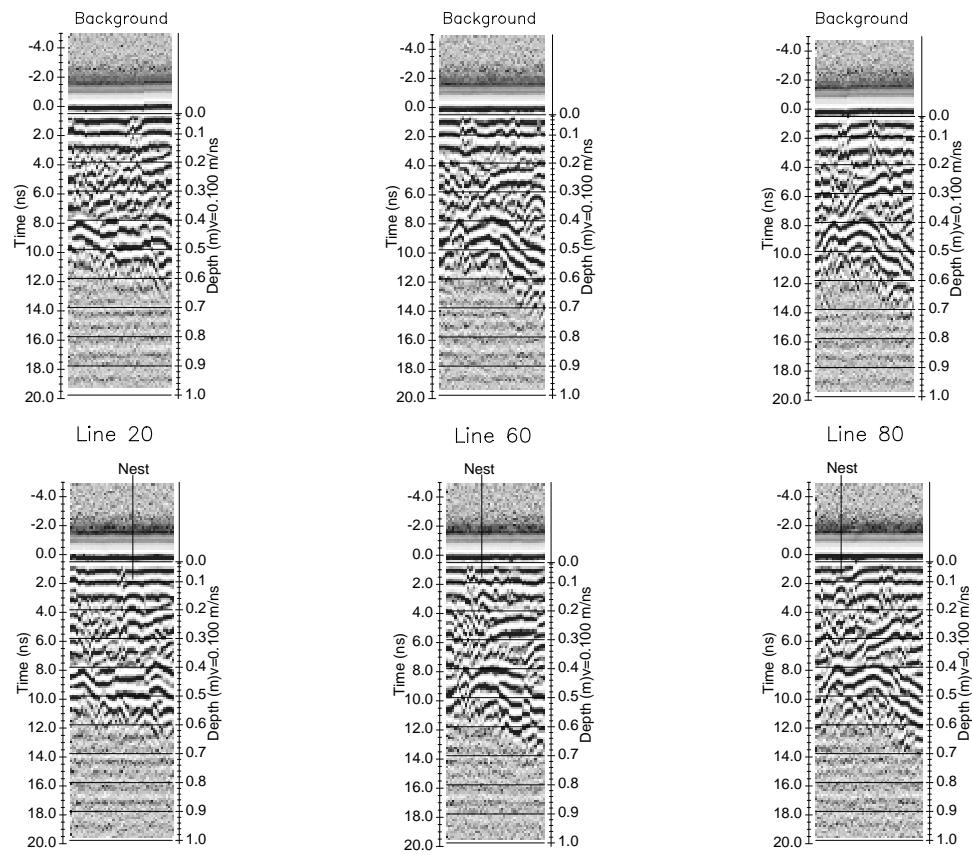


Figure 6. GPR profiles acquired during preliminary test before and after the mock nests were emplaced.



Figure 7. Multi-frequency FDEM data collection over test grid.

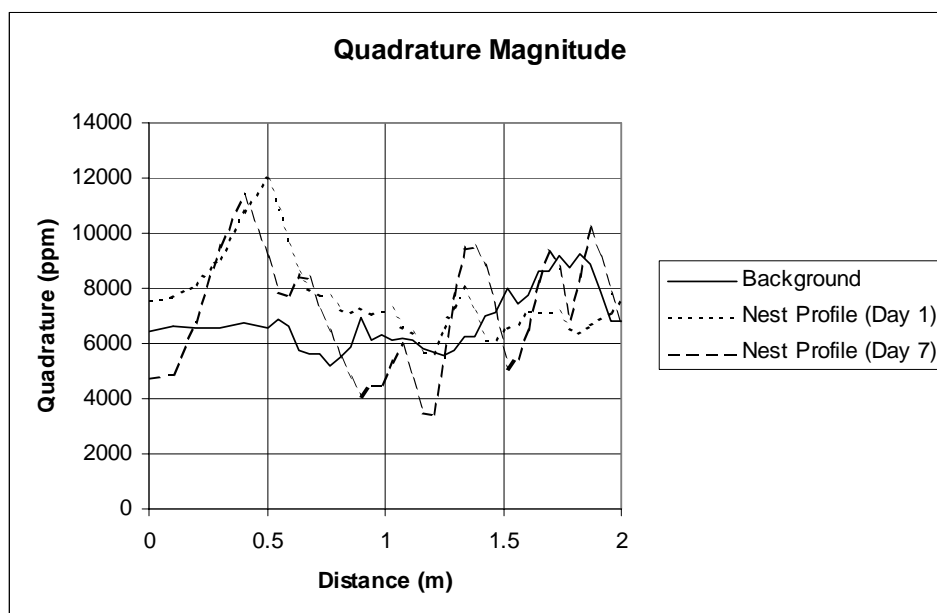


Figure 8. Multi-frequency FDEM background and nest profiles.

Seismic System

Point data were collected with the seismic system for analysis. The SSR showed promise in detecting nest locations when the detection geophone is placed close to the nest. Data collection for full coverage of an apron area is tedious for this system. However, spot-checking of areas of interest on an apron is a straightforward procedure. Figure 9 shows data collection in progress over the test grid.

The data shown in Figure 10 were collected at the WES test grid. Note the dramatic change in the signal when the sensor is placed over the nest. The apparent filtering is likely due to the disturbance of the soil after the nest was implanted. This radical change in signal appearance is what was hoped for in the Camp Shelby data.

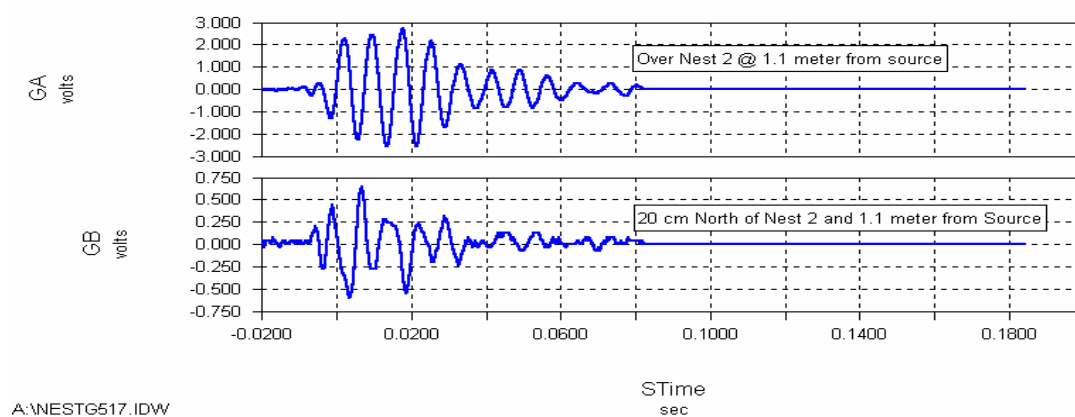
Thermal Imaging System

The thermal image system was used to collect data during different times of the day. The best thermal contrast was during dusk and just after sunrise. Area 1 in Figure 11 shows the thermal signature of a nest; however, Area 2 is also a nest site with a smaller number of eggs. The nest in Area 1 is detectable whereas the nest in Area 2 is not. Area 3 did not contain a nest but has a thermal signature similar to Area 1. Area 3 did contain more decaying organic materials near the surface, which

may be the source of the false positive. Due to limited optimal data collection times, the thermal imaging system was not taken to Camp Shelby.



Figure 9. Seismic data collection over test grid.



A:\WESTG517.IDW

Figure 10. Seismic data collected at WES test grid.

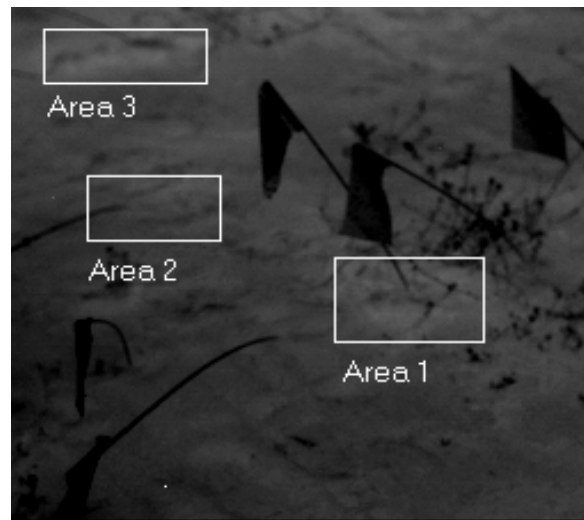


Figure 11. Thermal imaging data from test grid.

4 Camp Shelby Study

Survey Area

The surveys were performed 18-20 June 2001. The Nature Conservancy Camp Shelby Field Office biologists Deborah Epperson and Colleen Heise assisted during the investigation. They coordinated the visits to the gopher tortoise locations, aided with apron selections, carefully dug areas of interest to verify detected anomalies, and gave advice on dealing with the natural hazards at the sites (e.g., ticks, poison ivy). Tad Britt, Michael Hargrave, and Don Pitts (ERDC/CERL) were at the test site. Britt and Hargrave collected resistivity and magnetometer data across the gopher tortoise aprons. Personnel at the site from ERDC laboratories in Vicksburg included Jay Bennett, Dena Dickerson, Janet Simms, and Lewis Smithhart. Dickerson observed the collection techniques for possible applications to sea turtle nest detection. She also shared information on her experience with gopher tortoise habitats. Bennett, Simms, and Smithhart collected FDEM, GPR, and SSR data of the gopher tortoise aprons.

The geophysical surveys were performed over select tortoise burrow aprons within Firing Points 72 and 140, and Training Area 44. Training Area 44 was set aside in the 1980s as a refuge for tortoises, and mechanized training is not allowed within its boundaries. Table 1 provides a list of the burrow aprons surveyed. The general procedure for the GPR survey was to layout a minimum of three lines, beginning at about 25 cm from the tortoise burrow opening and extending at least 1 m. The lines were placed to cover the area on the apron where a nest would likely be found. The GEM-3 data were collected over a two-dimensional grid of survey lines.

Table 1. Tortoise burrow aprons surveyed and anomalies detected.

| Apron | GPR Anomaly | Comment |
|-----------------------|--------------------|---|
| Firing Point 72 | | |
| 1754 | | |
| No tag # | | Known nest |
| Firing Point 140 | | |
| 2 | X | |
| 3 | X | Nest found |
| 40 | | |
| 379 | | |
| 384 | X | |
| No tag #, west of 973 | | |
| 973 | X | |
| Training Area 44 | | |
| No tag # | | Known nest |
| 275 Round | X | |
| 1193 | | |
| 1196 | | |
| 146 Round | X | |
| 1271 | X | Mock tortoise nest |
| 1273 | | |
| 1274 | X | Seismic reflection anomaly; Nest found |
| 1275 | | |
| 1299 | | |
| 1300 | | |
| 1301 | | Seismic reflection anomaly; Nest found |
| 1302 | | |
| 1303 | X | Seismic reflection anomaly |

Geophysical Results

FDEM Results

The FDEM system was not able to detect either the known nest or the mock nest at Camp Shelby. However, it was useful in verifying the presence of metallic items around the aprons. Figure 12 shows the profile over the known nest at Firing Point 72 apron and the mock nest at Apron 1271 of Training Area 44.

GPR Results

The subsurface imaging capabilities of GPR and the shallow investigation depth and resolution obtainable using a high frequency antenna make GPR a feasible tool for detecting tortoise nests. The minimum depth of investigation using the 1000- and 1200-MHz antenna is about 5 cm, whereas the maximum depth achieved at this site is about 40 cm. The discussion below addresses only burrow aprons known to contain a nest or where an anomaly suggestive of a tortoise nest was detected.

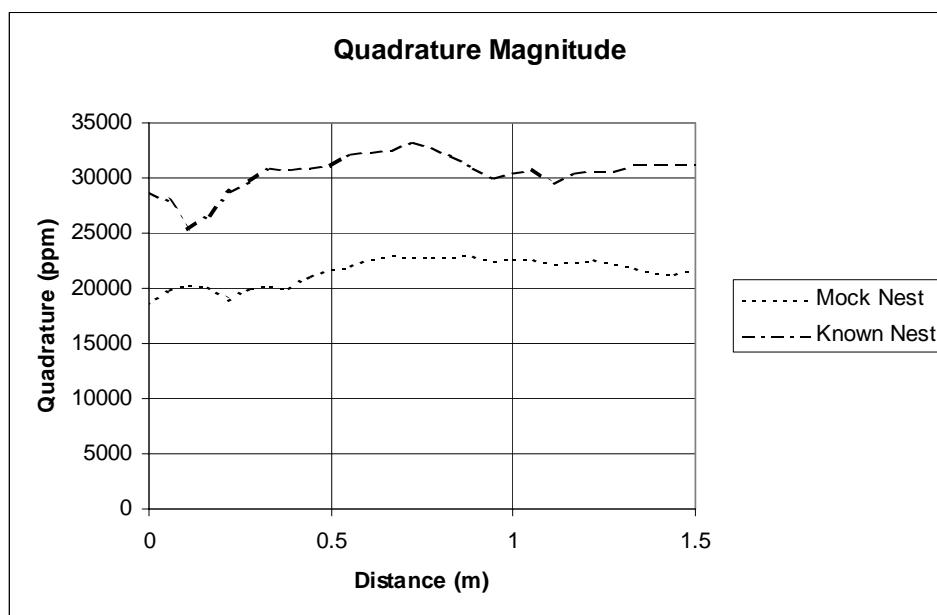


Figure 12. Mock Nest and Known Nest FDEM profile.

TRAINING AREA 44

Apron 1271

On the last day of surveying, staff biologist Deborah Epperson constructed a mock nest in Apron 1271 to test the capabilities of the different instruments to detect tortoise nests under local soil conditions. The nest was located approximately 40 cm directly out from the borrow opening and was about 10 cm in diameter. Five small chicken eggs were placed in the nest, with the shallowest egg about 10 cm below the ground surface. The investigators were not told where the nest was located on the apron; however, there appeared to be some remnant surface expression from the digging and watering (to compact the soil) of the nest. Several hours elapsed between the time the nest was constructed and the geophysical surveys were conducted. Three GPR profiles were obtained: two parallel lines positioned in line with the burrow, and one that ran diagonally across the apron. Refer to Figures 13, 14, and 15 for the general layout of the GPR survey lines for all aprons investigated at Training Area 44, Firing Point 140, and Firing Point 72, respectively. Figure 16 shows a typical layout at one of the Camp Shelby aprons. The GPR profiles collected over Apron 1271 are presented in Figure 17. The profile offset from the presumed location of the nest shows no indication of a nest being present. The data obtained along (1) the survey line positioned over the suspected location of the nest and in line with the burrow, and (2) the diagonal survey line indicate an anomaly where the nest is located. Both profiles also show a slight surface depression resulting from the recently dug hole. Note that it is the signature from digging the hole that is detected rather than a reflection from the eggs. This depression would also be expected from a nest constructed by a tortoise.

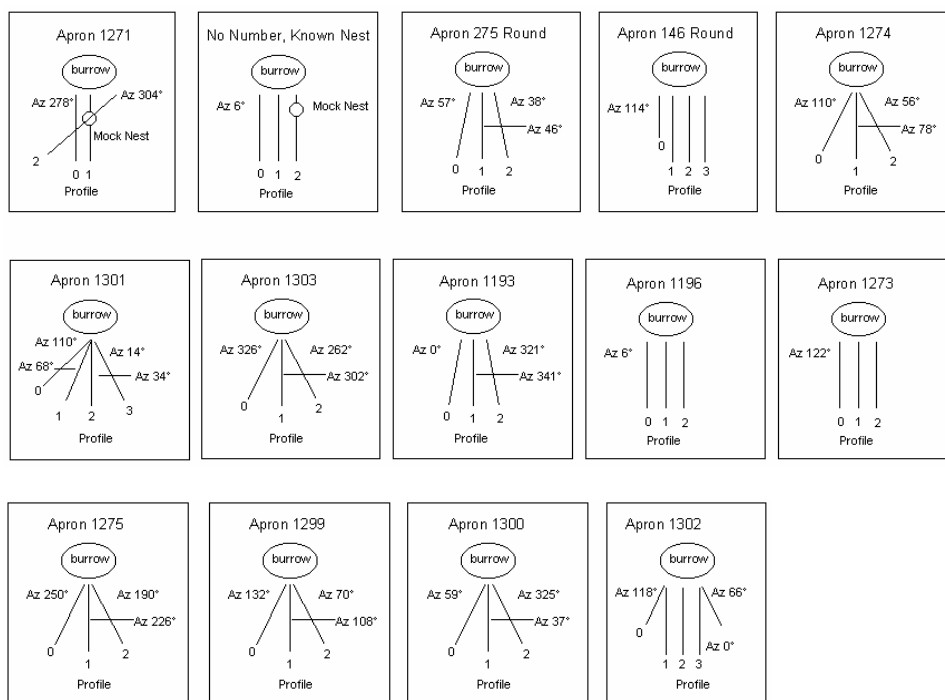


Figure 13. Layout of GPR profile lines on all aprons surveyed at Training Area.

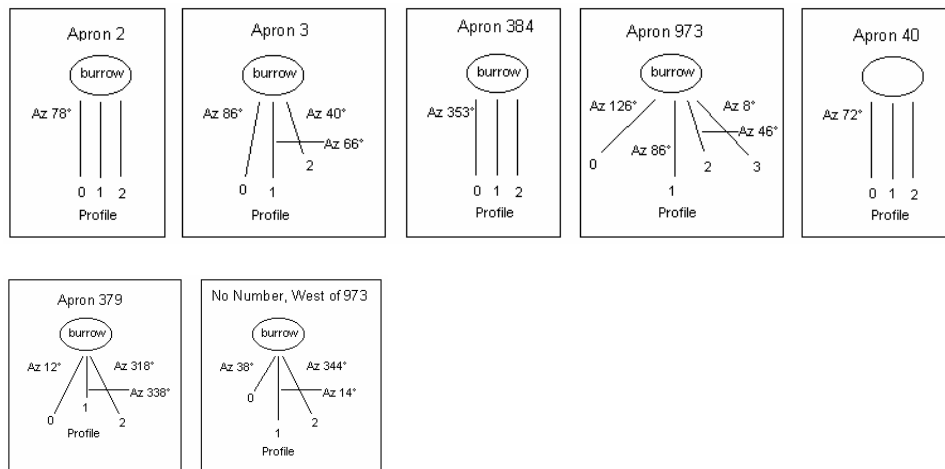


Figure 14. Layout of GPR profile lines on all aprons surveyed at Firing Point 140.

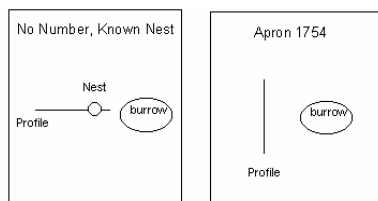


Figure 15. Layout of GPR profile lines on all aprons surveyed at Firing Point 72.



Figure 16. Typical GPR layout for aprons at Camp Shelby.

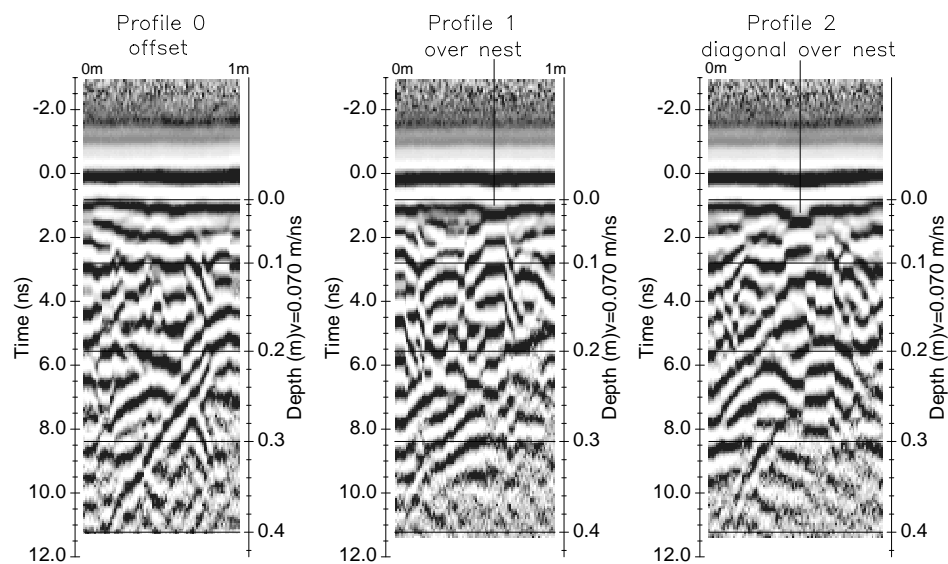


Figure 17. GPR profiles acquired over Apron 1271, Training Area 44, containing mock tortoise nest.

Apron No Tag Number, Known Nest

The GPR profiles acquired over this apron containing a known tortoise nest are presented in Figure 18. The nest is located on Profile 2 near the end of the line. Two features are present on all profiles. The first is a filled depression, located in about the center of each profile, and the other is mounded soil layers observed near the end of each line. The mounded feature is similar, although broader, than that observed over the mock tortoise nest and its location along Profile 2 is proximate to the known nest. Since the mounded feature is present on all profile lines, however, it is considered too large to represent a tortoise nest. If the nest was detected in the Profile 2 data within the mounded feature, then its possible location would be approximately 80 cm along the survey line and at a depth of about 14 cm.

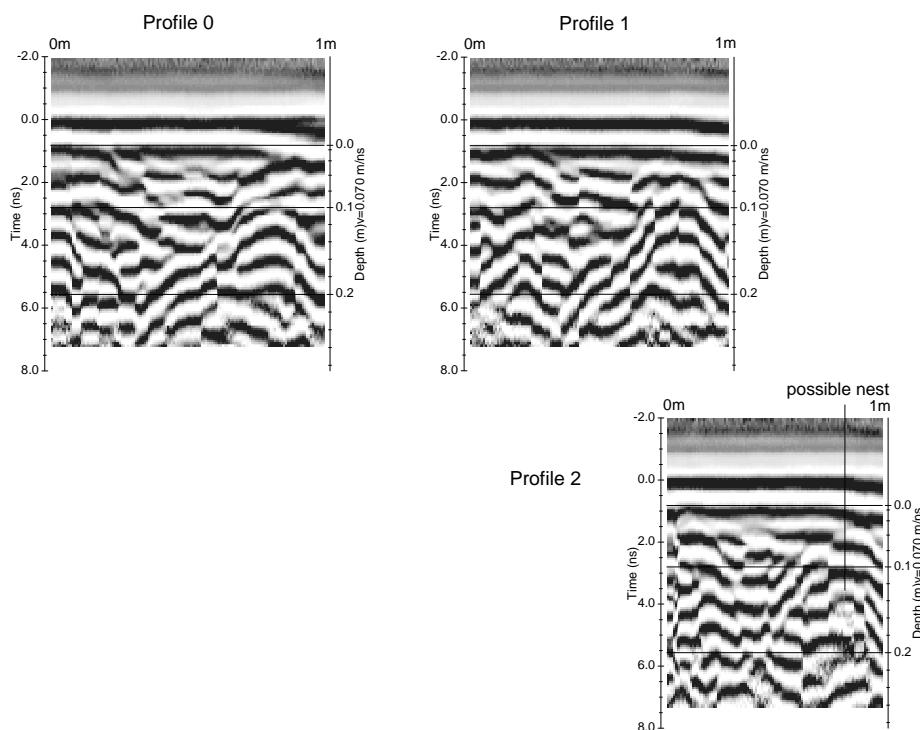


Figure 18. GPR profiles acquired over unknown apron number with known nest, Training Area 44.

Apron 275 Round

All three radar profiles acquired over this apron show a mounded feature with a depression overlying it (Figure 19). Although it is unlikely this feature is a nest, it was recommended that it be dug along Profile 2 at a distance 50 to 75 cm from the burrow opening. No nest was encountered when the site was probed and excavated.

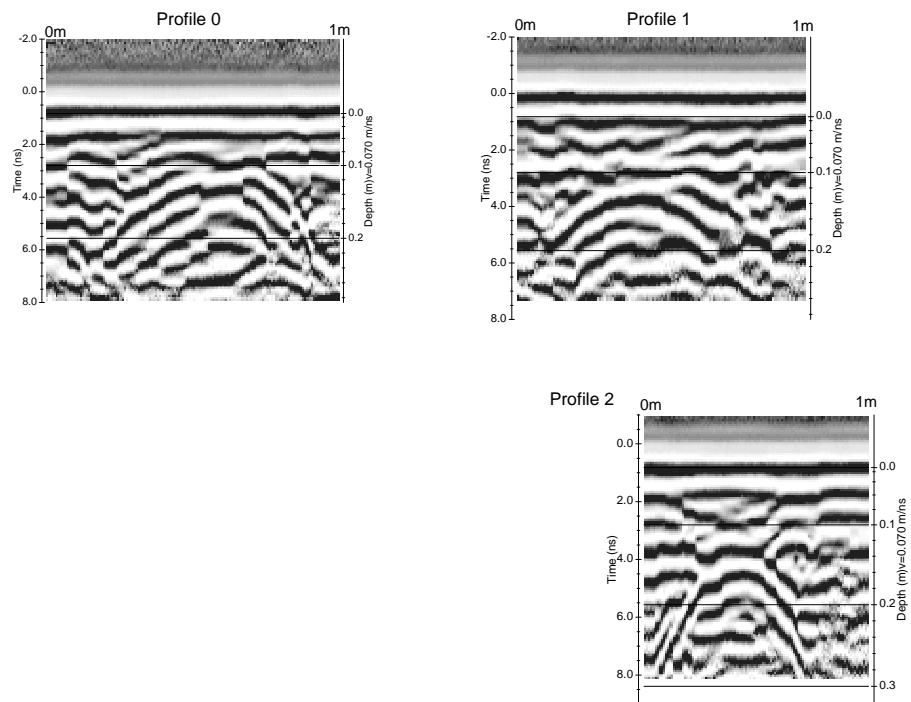


Figure 19. GPR profiles acquired over Apron 275 Round, Training Area 44.

Apron 146 Round

A common anomaly is also observed in the profiles collected at Apron 146 (Figure 20). The anomaly was investigated along Profile 3 at a distance 1 to 1.25 m from the burrow, but nothing was uncovered.

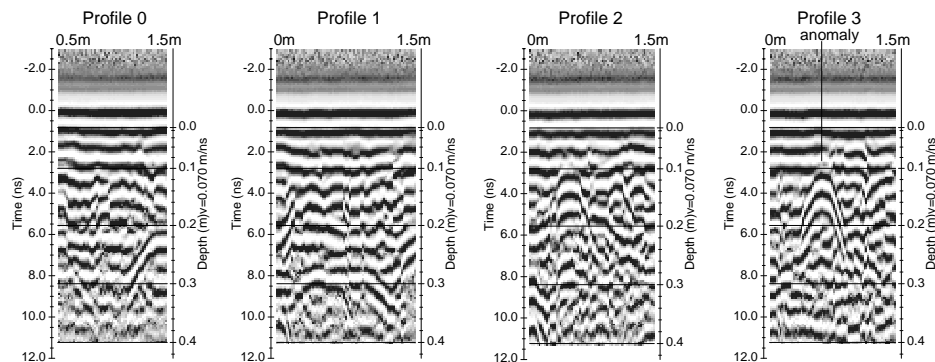


Figure 20. GPR profiles acquired over Apron 146, Training Area 44.

Apron 1274

Two anomalies were detected on Profile 0 (Figure 21). One is 20 to 50 cm from the burrow opening at an approximate depth of 20 cm, and the other is at a 50- to 75-cm distance about 8 cm below the surface. The seismic reflection technique also detected an anomaly on this apron. Excavation of the apron revealed a nest 40 cm from the burrow at a depth of 14 cm.

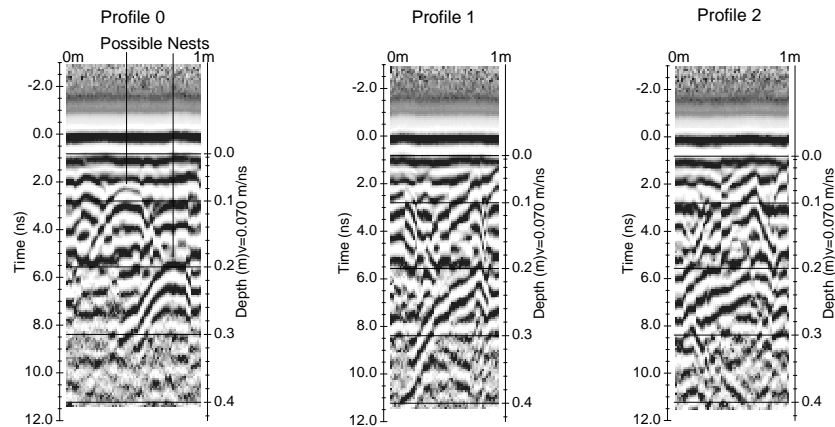


Figure 21. GPR profiles acquired over Apron 1274, Training Area 44. Nest discovered between Profiles 0 and 1.

Apron 1301

This apron was not originally cited as having a GPR anomaly indicative of a possible tortoise nest. The seismic reflection survey identified an anomaly, and the biologists discovered a nest 50 cm from the burrow at a depth of 10 cm. The nest to burrow heading was 44 degrees. An anomaly can be seen on each of the four radar profiles (Figure 22). The seismic reflection survey line is closest to GPR Profile 3. The nest was discovered between Profiles 1 and 2. The anomaly on Profiles 2 and 3 is likely caused by the same buried object and therefore is not considered to be a nest.

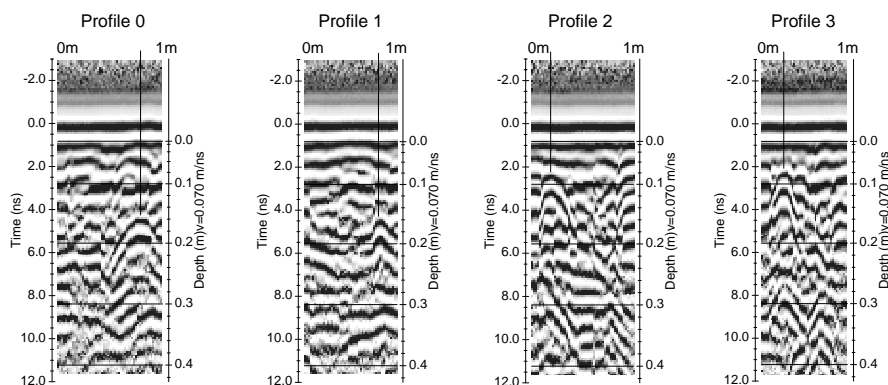


Figure 22. GPR profiles acquired over Apron 1301, Training Area 44. Nest discovered between Profiles 1 and 2.

Apron 1303

Two anomalies are present on each of the three radar profiles acquired at this apron (Figure 23). It is likely that the respective anomaly on each profile is caused by the same subsurface feature and probably does not represent a nest. It was still recommended, however, that both anomalies be dug along Profile 1 at distances of 20–50 cm and 50–75 cm from the burrow opening. As expected, no nest was uncovered. The seismic reflection survey detected anomalies about 45 and 65 cm out from the burrow along a path proximal to Profile 0.

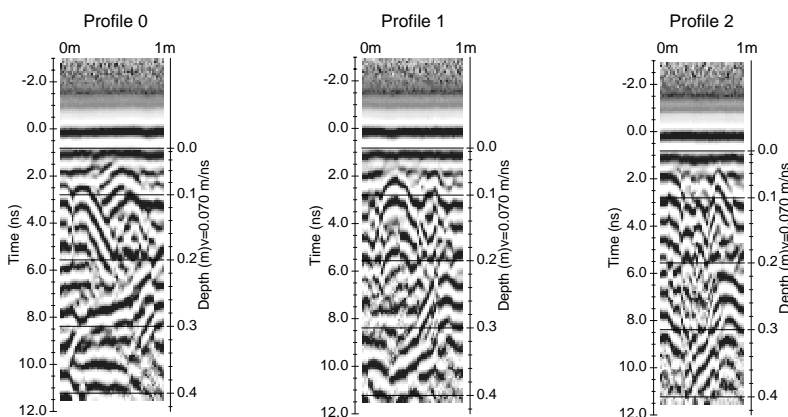


Figure 23. GPR profiles acquired over Apron 1303, Training Area 44.

FIRING POINT 140

Apron 2

Two very shallow anomalies are seen on Profile 0, but only one is considered a possible nest site (Figure 24). The anomaly is 75–100 cm from the burrow and is only 3-cm deep. It is recommended as a dig site.

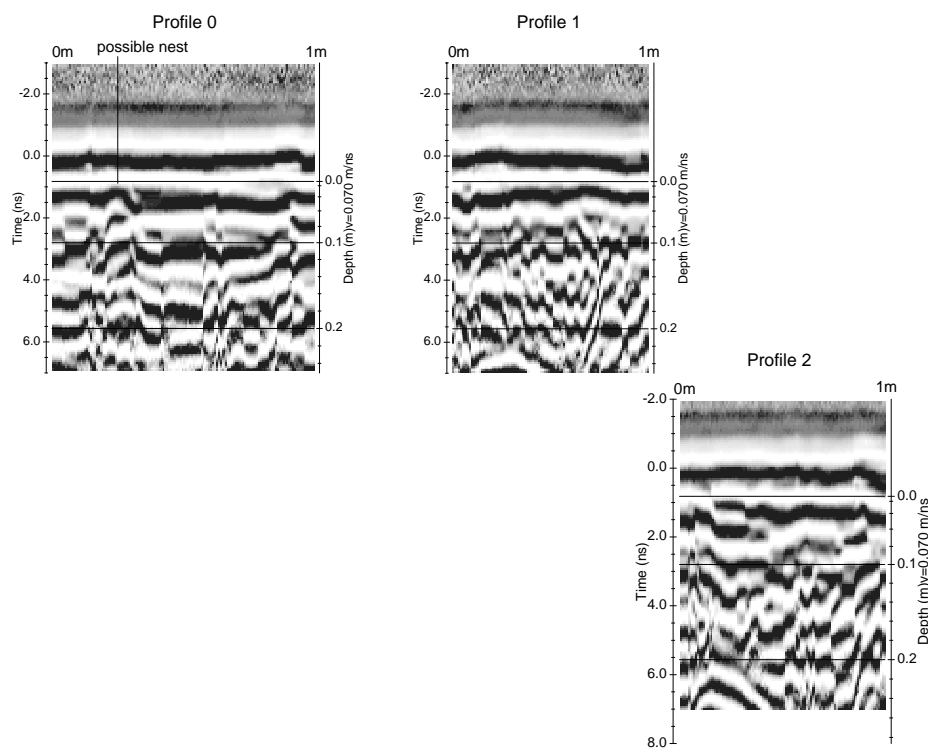


Figure 24. GPR profiles acquired over Apron 2, Firing Point 140.

Apron 3

A nest was uncovered on this apron, although not at the location suggested based on the GPR data. The profiles are presented in Figure 25. The GPR anomaly considered to represent a possible nest is seen on Profile 2 at a distance 25 to 50 cm from the burrow. The nest was discovered just east of Profile 1 and 70 cm from the burrow at a depth greater than 10 cm.

Apron 384

An anomaly identified on Profile 1 at a distance 25 to 50 cm from the burrow was thought to be a possible tortoise nest (Figure 26). However, no nest was uncovered when the apron was probed and excavated.

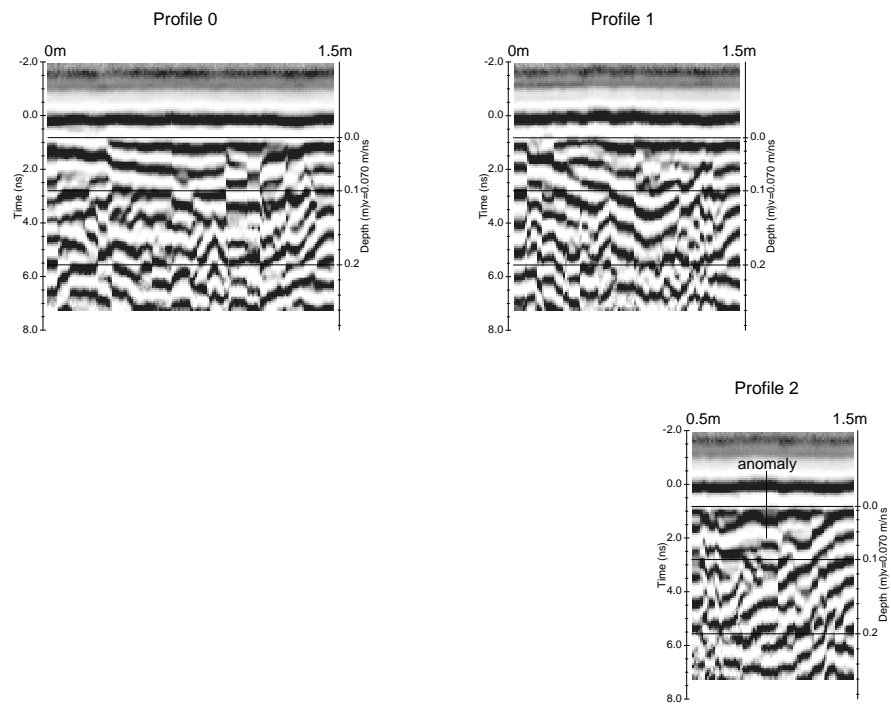


Figure 25. GPR profiles acquired over Apron 3, Firing Point 140. Nest discovered between Profiles 0 and 1.

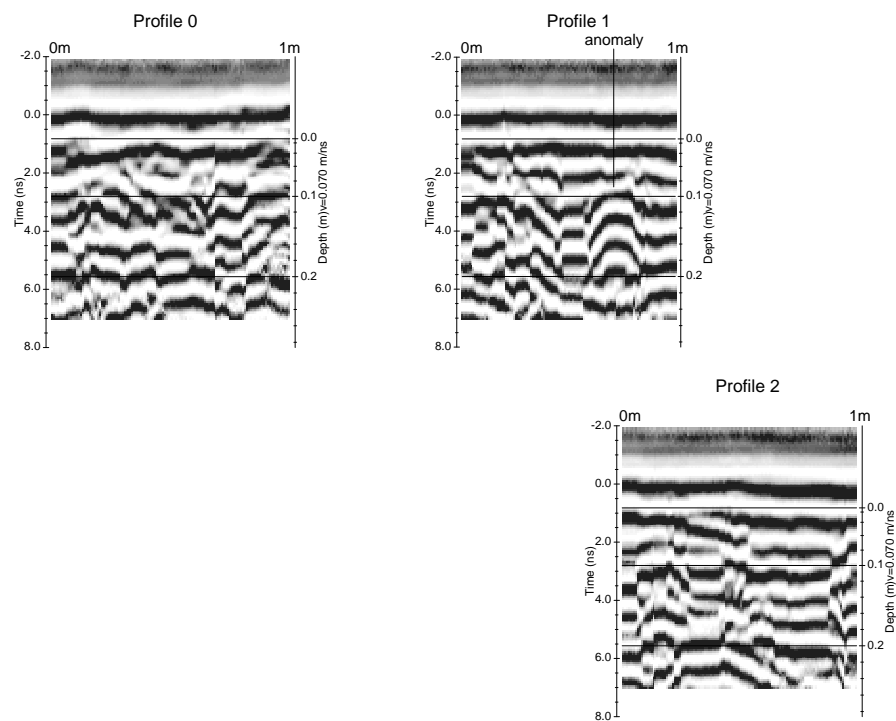


Figure 26. GPR profiles acquired over Apron 384, Firing Point 140.

Apron 973

The possible nest anomaly is seen on Profile 2 (Figure 27). This is not a strong anomaly, but it was still recommended for further investigation. No nest was found on this apron.

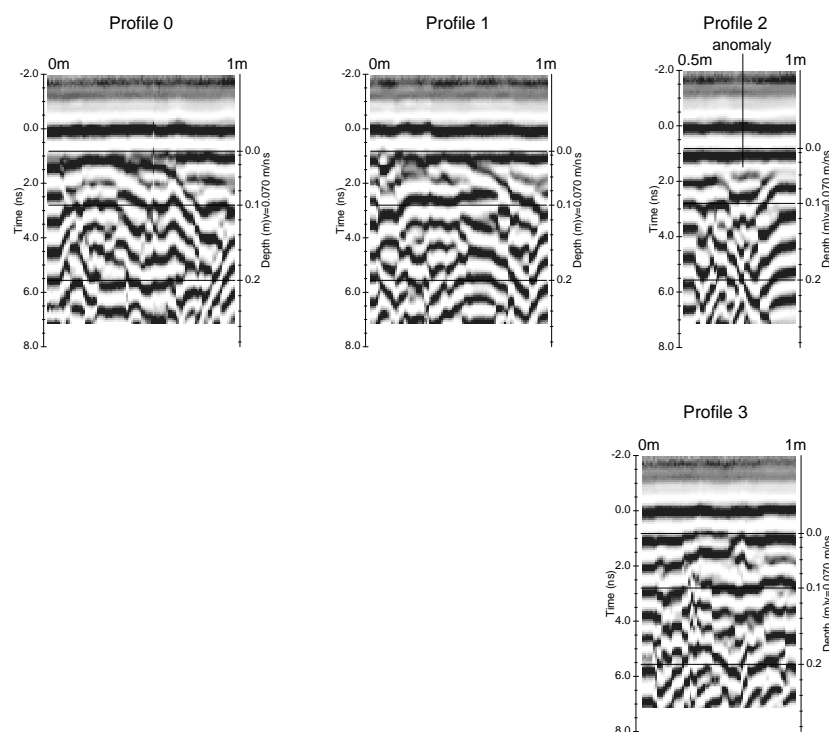


Figure 27. GPR profiles acquired over Apron 973, Firing Point 140.

FIRING POINT 72

Apron No Tag Number, Known Nest

This apron contains a known nest that was uncovered and the soil replaced immediately prior to the GPR survey. The profile in Figure 28 was acquired along a line directly in line with the burrow and nest. Unfortunately, no obvious signature indicates a nest.

It is possible that the digging activity may have disturbed the soil signature associated with the tortoise nest; however, signs of soil disturbance are generally detectable using GPR. Figure 29 is an example where digging has disturbed the subsurface soil structure. These two radar profiles were acquired over Apron 1754 and represent the same survey line before and after digging. Profile A was acquired before digging and exhibits an anomaly at 0.8 m and a depth of 18 cm. The anomaly

was considered a possible nest site, but nothing was found. The same line was surveyed after digging and Profile B shows no strong disturbance as was evident in Profile A.

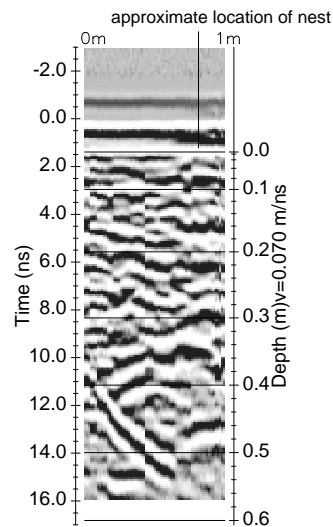


Figure 28. GPR profile acquired over known nest on unmarked apron, Firing Point 72.

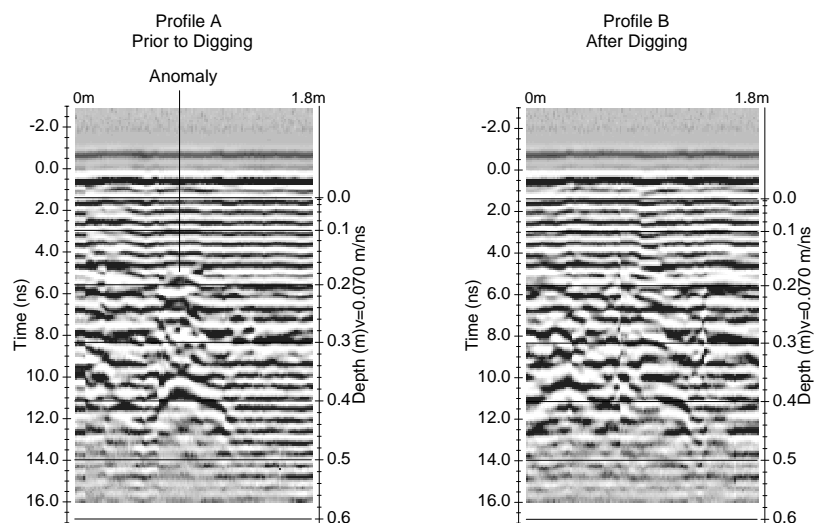


Figure 29. Comparison of GPR profiles acquired over an anomaly location prior to and after digging, Apron 1754, Firing Point 72.

Seismic Results

Figure 30 shows the data collected over the only known tortoise egg site tested at Camp Shelby. The blue signal was collected directly over the egg clutch, while the red geophone was about 30 cm away. The continuation and distortions of the blue signal (upper trace) indicates the multiple subsurface reflections from the eggs.

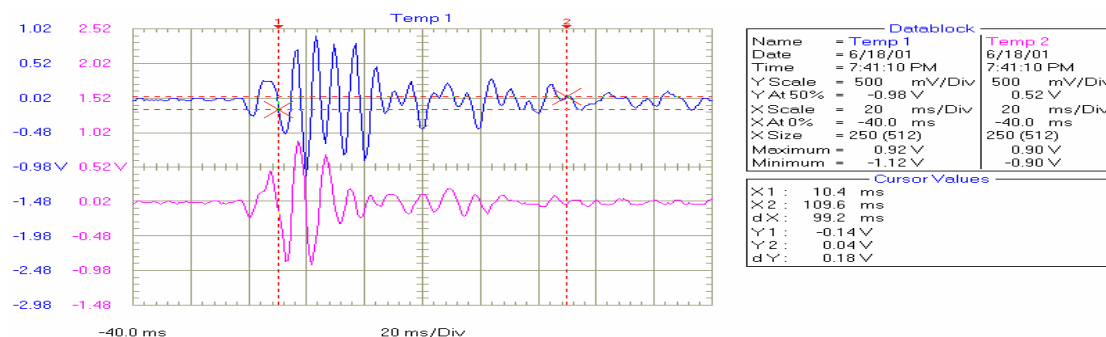


Figure 30. Known nest SSR data.

Figure 31 shows data collected at site 1273. A clutch may be under the blue geophone (upper trace).

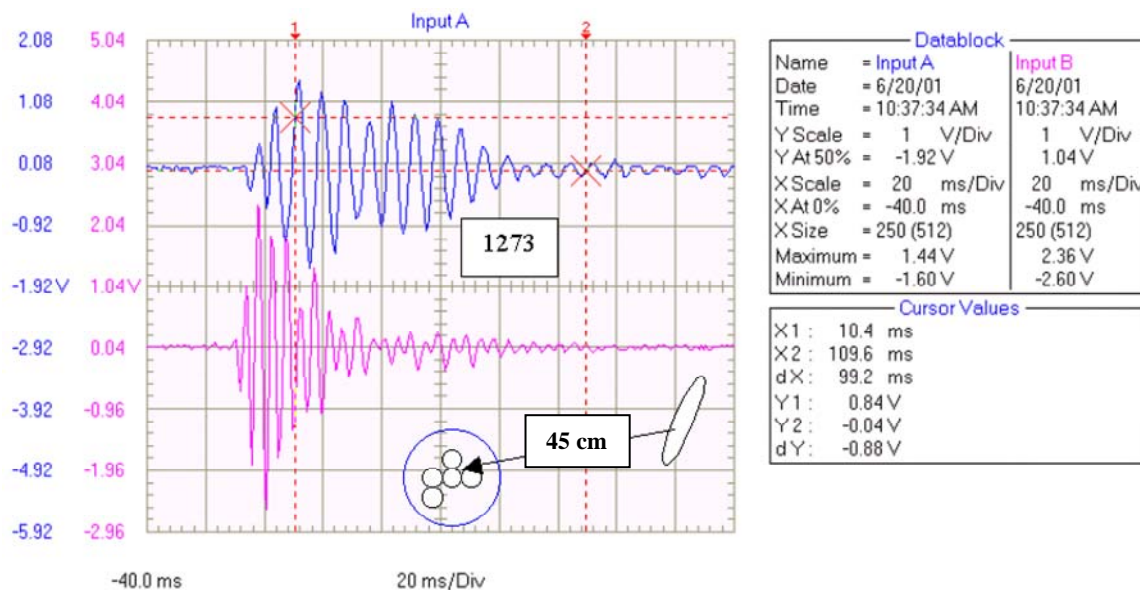


Figure 31. Site 1273 SSR data.

Figure 32 shows data collected at site 1274. A clutch may be under the red geophone (lower trace).

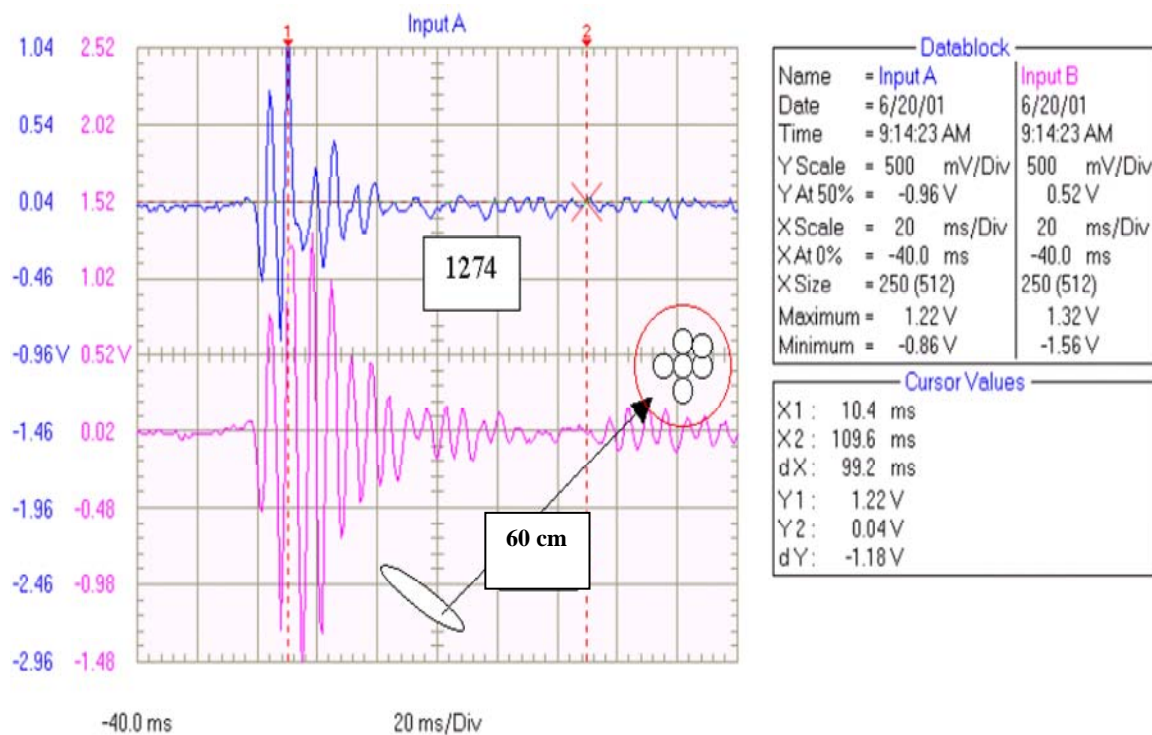


Figure 32. Site 1274 SSR data.

Figure 33 shows data collected at site 1300, another possible clutch site.

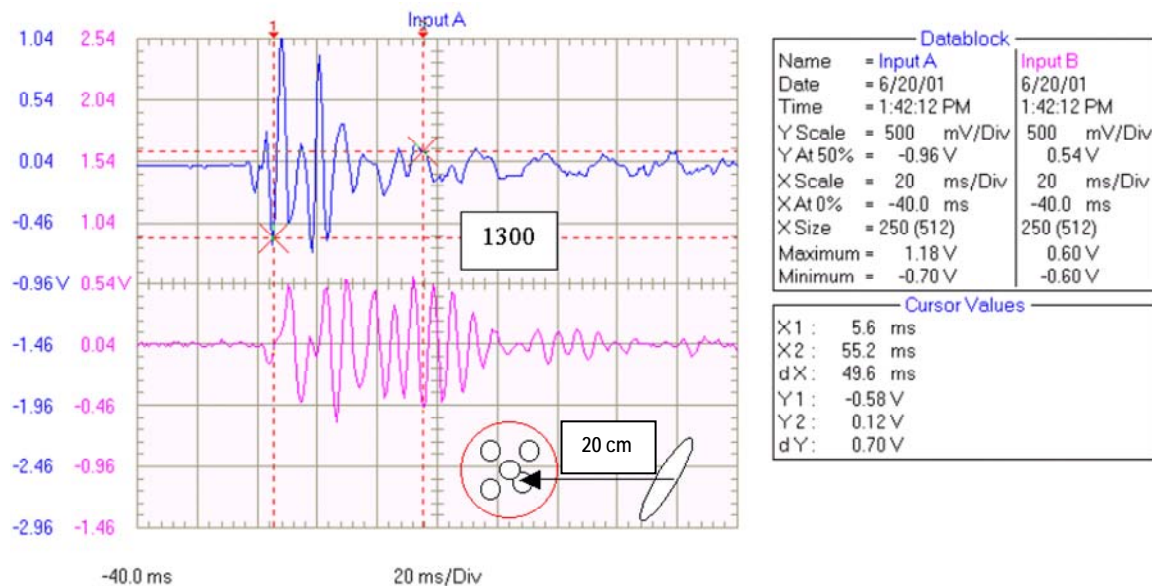


Figure 33. Site 1300 SSR data.

Figure 34 shows data collected at site 1301. There is a possible clutch beneath the Red sensor (lower trace) on site 1301.

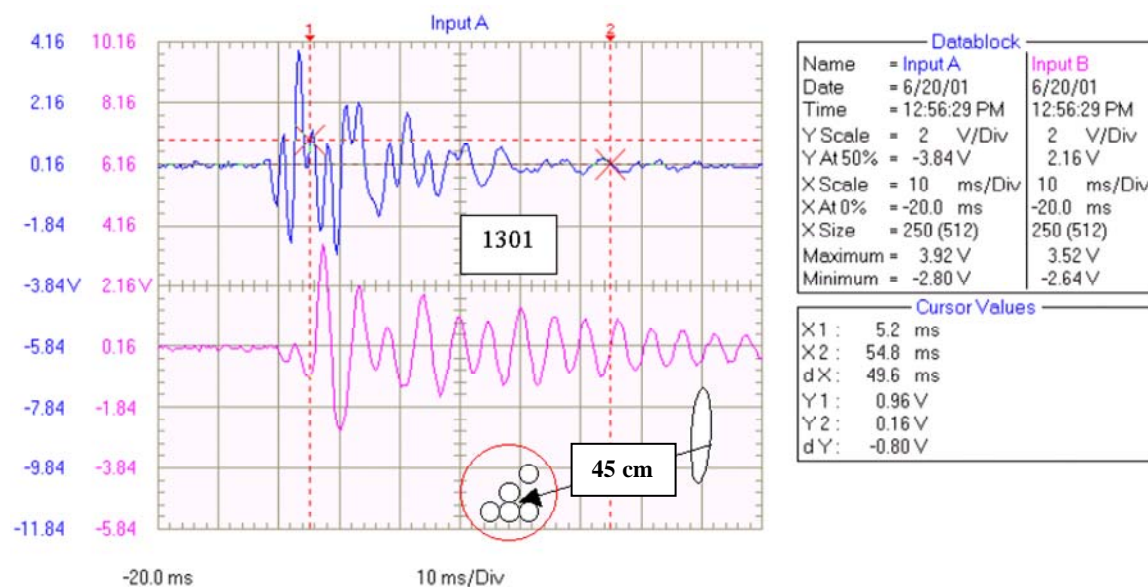


Figure 34. Site 1301 SSR data.

Figure 35 shows data collected at site 1303. It is suspected that this data from site 1303 may be a deep nest or rock cluster.

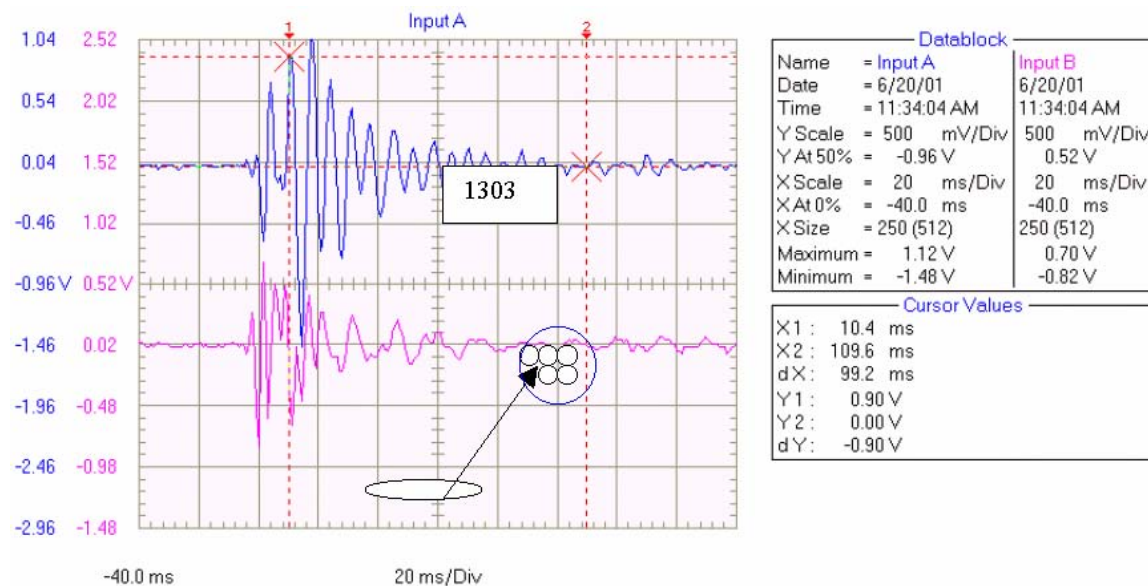


Figure 35. Site 1303 SSR data.

Figure 36 shows the data set from site 145. This data set is interesting because of the relatively large apparent signal amplification of the signal from the Red sensor (lower trace). This phenomenon is likely due to sensor coupling rather than signal reflection. However, a difference of this magnitude warrants further investigation.

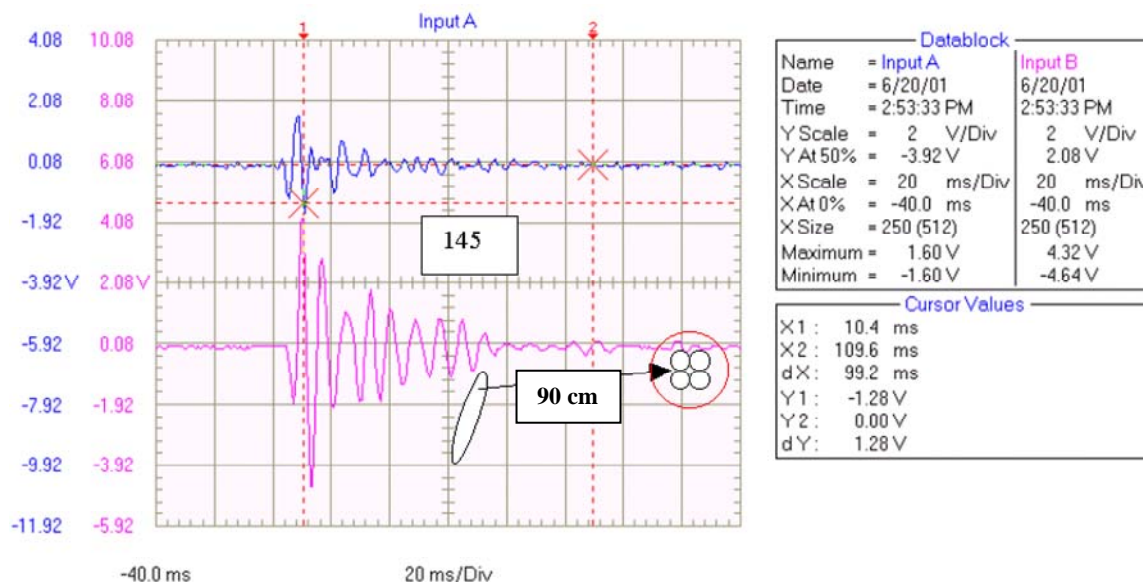


Figure 36. Site 145 SSR data.

Other sites investigated included: 275, 1193, 1196, 30, 03, 1350, 146, 1275, and 1272. Although not recorded, a “good” signal was detected at site 30. Excavation produced a cluster of inch-sized gravel about 12-cm deep.

The last SSR test conducted was on a burrow that contained a clutch of buried chicken eggs. The nest was detected; unfortunately, the data were not saved. The data closely resembled Figure 31.

This final set of data, shown in Figure 37, is from a post-test experiment on a nest of four small chicken eggs buried 16-cm deep in a consolidated sandy clay soil that contained a small amount of pea-sized gravel. After the eggs were implanted, the area was watered and left to stabilize during the day. The effect was to create a test site that more closely resembled the actual burrows at Camp Shelby.

Both geophones are 4 feet from the source and 12 cm apart. The red sensor (lower trace) is over the nest containing four eggs. It was noted that the geophones must be directly over the nest for a good return. If the sensor is moved more than a couple of inches from the center of the clutch, the reflections fade into the noise.

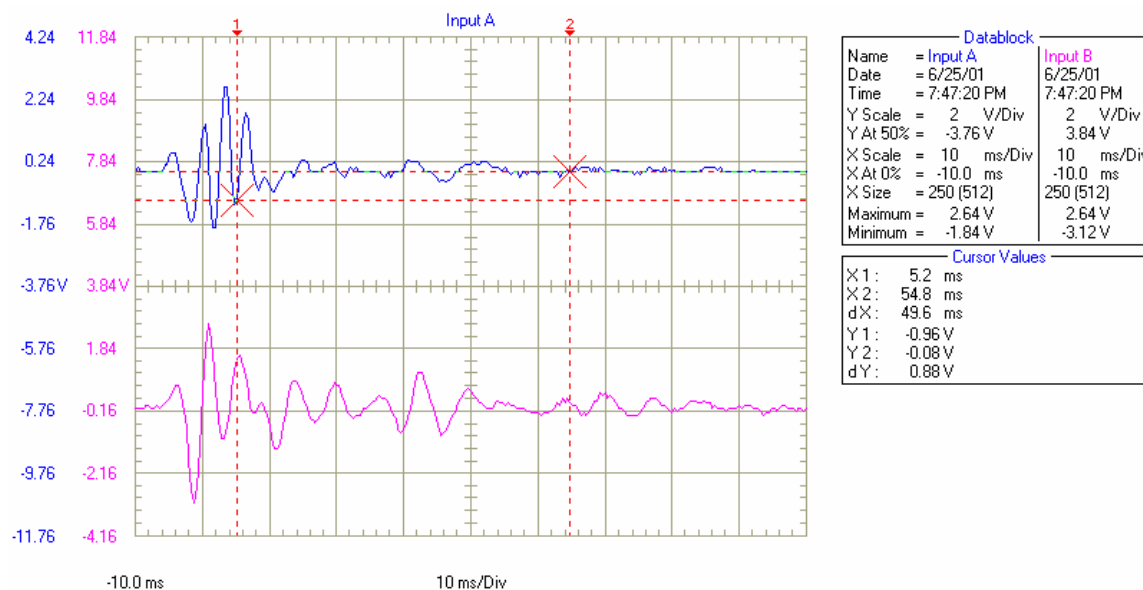


Figure 37. Mock nest SSR data.

Electrical Resistivity Results

All survey data were processed using Geoplot 3.0 software. This software is provided by the instrument manufacturer and is optimized for the data characteristics and processing objectives associated with archaeological survey. The processed data were exported into Surfer 7.0 to produce the image maps presented here.

The processing objective for the resistivity data was to detect and map small, potentially low-contrast features (e.g., pits) that are slightly higher or lower in resistivity than the surrounding soil. This was achieved by de-spiking the data and performing a highpass filter operation. The de-spiking routine in Geoplot removes outlier data values. Highpass filtering enhances the visibility of small, low-contrast features. The highpass filtered map has a mean value of zero. Approximately one-half the filtered data are positive (resistivity value greater than the local background) and one-half are negative (less than the local background). Positive and negative resistivity anomalies represent potential archaeological features and targets for archaeological investigation.

Figure 38 exemplifies the resistivity survey results. The sandy soil was characterized by resistance values that, after processing, ranged from -709 to +1292 ohms. In an effort to increase contrast sufficiently to detect subtle anomalies in Figure 38, values smaller than -400 are mapped as white and values greater than +400 are mapped as black.

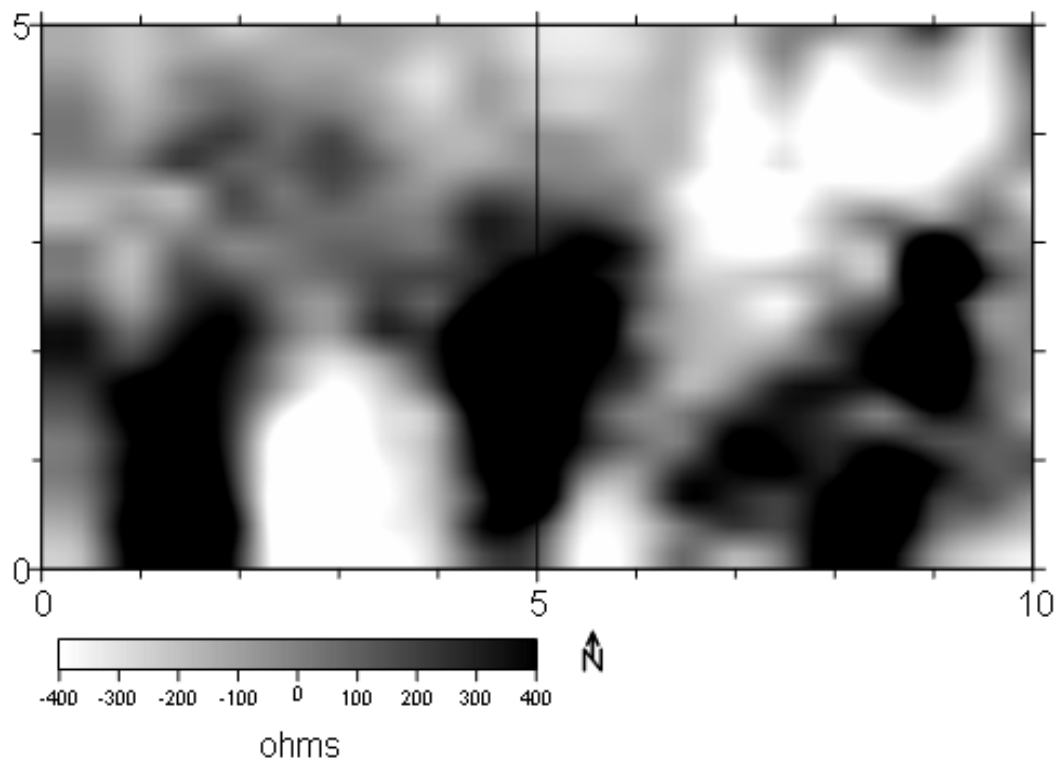


Figure 38. Representative results of electrical resistance survey providing no indications of the suspected nest.

The tortoise egg clutches, which exhibit a mean diameter of about 40 mm, represent very small targets for this type of resistivity survey. Resistance data were collected at 25-cm intervals. In most cases, one would expect the egg clutch (and associated soil disturbances) to influence the values of only two or three contiguous data points. It is highly unlikely that a subtle anomaly associated with an egg clutch would be detected against a background characterized by such a wide range of variation in resistance.

Magnetic Field Gradient

The processing objective for the magnetic data was to detect small, very low contrast features. This objective was achieved by first removing survey bias defects, interpolating the data to achieve symmetrical pixels, and then applying a 1-m-diameter Gaussian-weighted lowpass filter. The resultant map has a mean value of zero. Approximately one-half the filtered data are positive (corresponding to a local increase in magnetic field strength) and one-half are negative (corresponding to a local decrease in magnetic field strength). The statistical averaging associated with the lowpass filter also had the effect of further reducing the noise level (standard deviation) in the magnetic map.

Figure 39 exemplifies the results of the magnetic gradient surveys. To increase contrast and improve the potential for detecting subtle anomalies in Figure 39, values smaller than -0.8 are mapped as white whereas values greater than $+0.8$ are mapped as black. After processing, the actual data ranged from -2.73 to $+2.34$. Note, however, that the unprocessed data exhibited a much wider range in variation. During processing, values greater than $+3$ nT and smaller than -3 nT were removed, again in an effort to detect extremely low contrast anomalies.

In a magnetic survey, tortoise egg clutches would be expected to be manifest as weak negative anomalies. The eggs themselves should have no magnetic character. The negative anomaly would be associated with the egg's displacement of the local soil, which might have at least some intrinsic magnetic character. If the soil contains a substantial amount of iron, it might have a notable magnetic susceptibility, and a small void associated with the egg clutch would create a negative anomaly. If the soil has a low magnetic susceptibility, the presence of a void would probably not create a detectable anomaly.

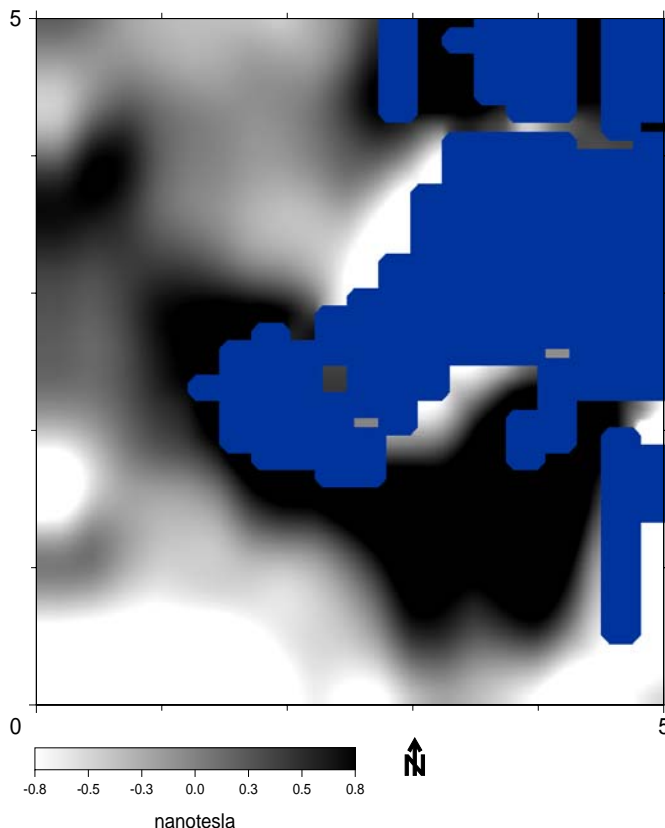


Figure 39. Representative results of the magnetic field gradient surveys. No indications of tortoise egg clutches were detected.

The inability of the magnetic survey to detect any indications of the suspected egg clutches is due primarily to the relatively wide range of variation in the magnetic character of the surrounding soil. Although the magnetic susceptibility of the soil is not known, a substantial amount of metallic trash was present in all survey areas. Such objects are associated with relatively strong anomalies, and this clutter essentially precludes the detection of very subtle anomalies that might be associated with the tortoise eggs.

5 Summary and Recommendations

Summary

Declining populations of the gopher tortoise, *Gopherus polyphemus*, have prompted extensive management efforts to increase egg clutch survival. It is estimated that as many as 88 percent of all clutches are being destroyed by predation (Cox et al. 1987). The most popular protection method, locating the clutch and protecting it from predation with a metal cage, requires the clutch be found without damaging or extensively disturbing the eggs.

Finding these clutches is not necessarily easy, even though they are most often buried in the apron of the burrow (Landers et al. 1980). When located in very sandy soils, the most common method is to carefully probe with a small wire. However, while the tortoise prefers sandy soils, it may also use loamy and even clay soils (Lo-hoefener 1982). Those nests in clay soils present significant difficulties in locating eggs, as probing is not successful and digging is difficult. Such higher-clay soils are characteristic of many tortoise habitats in the federally listed western populations, including those at Camp Shelby, MS.

Attempts were made in June 2001 to locate gopher tortoise nests in clay soils using instrumentation methods developed for other disciplines. This research was relevant to conservation needs for the federally threatened *G. polyphemus* population at Camp Shelby and elsewhere within that area. These methods were: electrical resistivity (ER), magnetic field gradient, frequency domain electromagnetic (FDEM), ground penetrating radar (GPR), shallow seismic reflection (SSR), and thermal imaging (TI). The methods were tested under laboratory conditions prior to field testing. Each of these methodologies was applied in one or more tests, and the results of each are summarized below.

Geophysical Methods

A geophysical survey consisting of electromagnetic (EM) and GPR was performed at Camp Shelby to determine if either technique is suitable for locating tortoise nests. The preliminary evaluation at WES and survey of a mock nest placed within Apron 1271 at Camp Shelby indicated that GPR was capable of detecting nest-like features. Although the GEM-3 performed marginally during the preliminary evalua-

tion, it was decided to use it at Camp Shelby since the soil type did not closely match that of the test site at WES.

The evaluation at Camp Shelby indicates that the GEM-3 EM instrument did not perform well in detecting the type of anomaly associated with a nest; however, GPR performed slightly better. The 1000- and 1200-MHz antennas used have the resolution capabilities to image the small diameter tortoise nests at the shallow depths where they are expected to be encountered. The GPR detects disturbances in the subsurface caused by both natural and man-made objects. Natural objects can include lithology, tree roots, animal burrows, and tortoise nests. Unfortunately, natural objects such as tree roots can produce an anomaly similar to that of a tortoise nest. If the same anomaly appeared on more than one radar profile, it was generally not considered a possible nest since the nests are small in diameter and the survey line spacing was greater than the diameter of a typical nest. It was recommended, however, that some aprons displaying the same anomaly on more than one profile be dug. Of the eight aprons that had GPR anomalies recommended for further investigation, four were not expected to contain a nest because the anomaly was either detected on multiple profile lines or smaller than what a nest would produce. No nest was found on Aprons 2, 146 Round, 275 Round, 973, or 1303. A nest was located on two of the remaining four aprons (3, 1274). The nests that were discovered were not located along the same azimuth as suggested by the GPR data, although the distance from the burrow was within the specified range. No reference information pertaining to survey points on the aprons was provided to the biologists except that the GPR profiles extended from the burrow along a specified direction. However, the suggested azimuth and known azimuth of the nest could vary significantly depending on which point on the burrow was used to measure the angle. In both cases, the GPR profile direction and the nest-to-burrow azimuth varied by 30 degrees.

One nest was detected on Apron 1301 based on results of the SSR survey. Review of the GPR data did not indicate a strong anomaly along any of the profile lines that is suggestive of a tortoise nest.

Although GPR was only partially successful in detecting tortoise nests, it is possible that a greater success rate may be achieved by modifying the survey procedure. It is suggested that, if GPR is to be used in the future, profiles be collected using denser line spacing. Greater coverage would eliminate the possibility of missing a nest. With regard to equipment, operation of the Noggin 1000 system would be easier with a handle attached to the antenna rather than a cart.

Seismic Method

Expectations of an easy search were short-lived once the SSR system was in the field at Camp Shelby. The gravel, tree roots, and a mixture of both hard and loose soils and inclined surfaces on the aprons combined to make signal collection and field processing unexpectedly challenging. The salient signals that heralded a nest site at the WES test area proved elusive on the actual burrows. The lack of any gratification (no idea if the burrow being surveyed even had a nest) for research efforts and the 90+ °F temperatures gradually took a toll on enthusiasm for the field study. Although this initial trial was somewhat disappointing, the overall effort proved to be a valuable learning experience.

This system does show promise for locating tortoise nests. The equipment is relatively inexpensive and easy to deploy, and the technology is simple. To be a viable and user-friendly system, however, some retooling is recommended:

1. Lighter, cheaper sensors
2. Four or more sensors instead of two to speed up data collection
3. A laptop computer with an analog/digital (A/D) card to replace the amplifier and oscilloscope. A computer would collect the data, so real-time computer analysis could be achieved, and decisions could be made in the field about the need for further probing or excavation. Transfer functions from typical nest sites at Camp Shelby, for example, could be compared with the signals being collected to determine the probability of a nest at the site being tested. Data can be easily saved for in-depth analysis.

Electrical Resistivity

Resistivity surveys (Heimmer and De Vore 1990) introduce an electrical current into the ground and measure the ease or difficulty with which the current flows through the soil. The unit of measure is the ohm. Resistivity is governed by the number and mobility of free charge carriers, principally soluble ions. The simultaneous availability of soil moisture and soluble salts determines the free charge carrier concentration in the soil. The mobility of the soluble ions is governed by soil moisture content, soil grain size, temperature, soil compaction, and the surface chemistry of the soil grains (Somers and Hargrave 2001).

Electrical resistivity is often useful in detecting subsurface archaeological features including pits, graves, and architectural remains. The Geoscan RM15 instrument used in this study is designed for archaeological applications. Unfortunately, the RM15 is not designed for electrode spacing of less than 25 cm, whereas detection of an egg clutch would probably call for very closely spaced readings collected using

probes spaced at 10 cm. Additionally, the sandy soil was characterized by a wide range of variation in resistance, and this prevented detection of small, low contrast anomalies that could be associated with a tortoise egg clutch.

Magnetic Field Gradient

Magnetic field gradient surveys (Bevan 1998) are essentially mapping deviations from uniformity in the earth's magnetic field. These change continuously through time, and short-term changes are usually greater than the distortion associated with archaeological features. Temporal change must be removed from the survey data to reveal distortions associated with archaeological phenomena (Somers and Hargrave 2001). Surveys are typically performed with two magnetometers, one to record the time-variable component, the other to record the spatial data and time-variable component. The latter component is removed from the survey data by subtraction. The Geoscan FM-36 used in this study included two fluxgate sensors measuring in nanoTeslas. While this method is successful in finding subterranean cultural features, the abundance of ferrous materials associated with military activities minimized the potential for detecting very small, low-contrast anomalies that might be associated with an egg clutch.

Frequency Domain Electromagnetic

The GEM-3 used in this analysis is a multi-frequency FDEM. The collection of multi-frequency FDEM data allows for EM induction spectroscopy (EMIS) of the targets and background materials. The EMIS signatures are characteristic of the object's geometry and material composition and consist of complex (in-phase and quadrature) frequency responses. These EMIS signatures can provide a method to discriminate items of interest based on their geometry and material composition. The frequencies used during the analysis were 150, 510, 990, 2430, and 8370 Hz. Test grid results were questionable. In the field trials this method appeared unsuitable, though it was excellent for finding metal artifacts in the burrow aprons.

Ground Penetrating Radar

Ground penetrating radar images the subsurface by transmitting an EM pulse into the earth and measuring the return signal. The frequencies employed in GPR typically range from 10 to 1000 MHz. While in the earth, the EM signal undergoes refraction, reflection, scattering, and dispersion. Contrast in the dielectric permittivity at material boundaries causes the EM wave to be reflected and refracted.

Soil conductivity is a major factor in determining if GPR can be used successfully at a site. High conductivity soils, such as those with a high clay and moisture content,

can significantly attenuate the EM signal and frequently render GPR virtually useless.

A Sensors & Software, Inc. Noggin system with a 1000-MHz antenna and a PE1000 with a 1200-MHz antenna system were used to collect the GPR data. Both the transmitter and receiver antennas are contained in one unit mounted on a cart that is pushed along the surface at a slow walking speed. The PE1000 system allows more flexibility in survey design and data acquisition; however, it is more labor intensive and requires experience. For both studies, the GPR survey was performed in reflection mode with the antennas oriented perpendicular to the survey line.

In reflection profiling, the transmitter and receiver antennas are kept a fixed distance apart and both antennas are simultaneously moved along the survey line. When using the Noggin system, a wheel odometer incorporated into the system was used to monitor the distance traveled and initiate data sampling at 1.25-cm increments. With the PE1000 system, data were collected at a user-specified sampling rate and distance was controlled by placing fiducial markers in the data at known distances. The time (nanoseconds) required for the EM wave to travel through the subsurface and return to the receiver is recorded at each sample station. The GPR profile is constructed by plotting the received signal against two-way travel time at each sample station along the survey line. Under laboratory conditions with homogeneous sand, this system showed promise that was partially verified in field application. GPR indicated known and planted clutches at Camp Shelby as well, but did not strongly indicate new clutch locations. Further study with this system is indicated.

Shallow Seismic Reflection

This method, in the development stage, differs from classical seismic reflection. Matched geophones are placed in the test area that receive a signal from a nearby seismic source. Received signals are compared for differences that indicate reflections from a subterranean anomaly. In a limited area, seismic signals from the point source will show only minor frequency and amplitude deformation as they propagate across a homogenous field. If the field contains anomalies, then reflections from these anomalies will combine algebraically with the primary source waves to create a resultant wave shape that is distinctly different from the source wave. Size, hardness, shape, and distance can affect the appearance of this composite waveform. SSR was collected using two matched Model L22 Geospace geophones with brass bases, a dual-channel OPA-9 seismic amplifier set for a gain of 18 dB, a Fluke Model 97 scopemeter, a laptop computer with FlukeView software, and a shop-made seismic source—a single point, electronically controlled vertical plunger. This method showed great promise under laboratory conditions with homogeneous

sand, finding planted clutches with accuracy. In field application with clay soils it was unsuccessful, though anomalies were noted, usually egg-size rocks or clumps of organic matter.

Thermal Imaging

Using the TI method for nest location is based on the assumption that the thermal conductivity of the eggs is different than the surrounding soil. This contrast would be manifested by a thermal anomaly on the ground surface above the egg clutch. The equipment used in the analysis was a Thermacam SC1000 developed by FLIR Systems, Inc. The SC1000 has a 256 by 256 element focal plane array. The spectral range of the system is from 3.4–5.0 μm . The detector is Stirling cooled to 70 °K. In the preliminary WES site test, the results from TI were nonspecific with degraded organic matter returning signals similar to planted egg clutches; therefore, the method was excluded from the field trial.

Recommendations

Though all instrumentation methods have proven worth within their dedicated disciplines, none were truly successful at locating *G. polyphemus* clutches in the field in Southern Mississippi. Ground penetrating radar appeared the most viable, though the particular methods used could not be called successful in this trial. Thus, reliance on any of these techniques is not recommended for critical surveys intended to accurately locate tortoise nests and egg clutches. It is to be hoped that future refinements of the technologies will improve in accuracy and reliability with respect to the detection of small, low-contrast targets such as tortoise eggs, and provide a tool to be applied in tortoise conservation activities, and in management of tortoise populations on Army lands.

References

- Auffenburg, W. 1978. In: McDiarmid, R.W. (ed.), *Rare and Endangered Biota of Florida. Vol 3: Amphibians and Reptiles*, Univ. Presses of Florida, Gainesville, FL, pp 33–35.
- Auffenburg, W. and R. Franz. 1982. "The status and distribution of the gopher tortoise (*Gopherus polyphemus*)," pp 95-126. In: R.B. Bury (ed.). *North American Turtles: Conservation and Ecology*, U.S. Fish and Wildl. Serv., Wildl. Res. Rep. 12.
- Auffenburg, W., and J.B. Iverson. 1979. In: Harless, M. and N. Norlock (eds.). *Turtles: research and perspectives*, Wiley-International, New York.
- Bevan, Bruce W. 1998. Geophysical Exploration for Archaeology: An Introduction to Geophysical Exploration. Special Report No. 1. U. S. Department of the Interior, National Park Service, Midwest Archeological Center, Lincoln, NE.
- Butler, J.A., and T.W. Hull. 1996. "Reproduction of the Tortoise, *Gopherus polyphemus*, in northeastern Florida." *Journal of Herpetology* 30(1):14-18.
- Cox, J., D. Inkly, and R. Kautz. 1987. Ecology and habitat protection needs of gopher tortoise (*Gopherus polyphemus*) populations found on lands slated for large-scale development in Florida. Florida Game and Fresh Water Fish Comm. Nongame Wildlife Tech. Rpt. No. 4, Tallahassee, FL.
- Dietlein, N.E., and R. Franz. 1979. "Status and habits of *Gopherus polyphemus*," *Desert Tortoise Council Pro.*, 1979 Symp., pp 175-180.
- Ernst, C.H., and R.W. Barbour. 1972. *Turtles of the United States*. The Univ. of Kentucky Press, Lexington, KY.
- Epperson, D., and C. Heise. 2001. Development of habitat-based population studies of the gopher tortoise. Unpublished Report. U.S. Army Construction Engineering Research Laboratory, Champaign, IL.
- Geophex, Ltd. (1998). "GEM-3 instruction manual," Geophex, Ltd., Raleigh, NC.
- Heimmer, Don H., and Steven L. De Vore. 1995. Near-Surface, High Resolution Geophysical Methods for Cultural Resource Management and Archeological Investigations. U.S. Department of the Interior, National Park Service, Rocky Mountain Regional Office, Division of Partnerships and Outreach, Interagency Archeological Services, Denver, CO.
- Landers, J.L., W.A. McCrea, and J.A. Garner. 1982. "Growth and maturity of the gopher tortoise in southwestern Georgia," *Bull. Florida State Mus. Biol. Sci.* 27:81-110

- Linley, Terry A., and Henry R. Mushinsky. 1986. "Organic composition and energy content of eggs and hatchlings of the gopher tortoise," *Fish and Wildlife Research* 13, 113-128.
- Lohofener, R. 1982. "Gopher tortoise ecology and land use practices in southern Desoto National Forest, Harrison County, Mississippi," *In*: Franz R. and R. Bryant (eds.). *The Gopher Tortoise and Its Sandhill Habitat*. Proc 3rd. Ann. Mtg., Gopher Tortoise Council, Florida State Museum, Gainesville, FL, pp 50-54.
- Scollar, Irwin, A. Tabbagh, A. Hesse, and I. Herzog. 1990. *Archaeological Prospecting and Remote Sensing*, Cambridge University Press, Cambridge, UK.
- Somers, Lewis, 1997. Geophysical Investigations at Archaeological Sites 14RY3183, 14RY3193, 14RY5155, and 14GE328, Ft. Riley, Kansas. Report submitted to U.S. Army Construction Engineering Research Laboratory (CERL), Champaign, IL, by Geoscan Research
- Somers, Lewis, and Michael L. Hargrave. 2001. "Magnetic and Resistivity Surveys of Four Sites," *In*: Bruce S. Idol and Stevan C. Pullins, *Phase II Archaeological Evaluation of 25 Sites, Fort Bragg and Camp Mackall, Cumberland, Harnett, Hoke, and Moore Counties, North Carolina*, prepared for U.S. Army CERL by TRC Garrow Associates, Inc. and The William and Mary Center for Archaeological Research.
- Wilson, D.S., H.R. Mushinsky, and R.A. Fischer. 1997. Species profile: gopher tortoise (*Gopherus polyphemus*) on military installations in the southeastern United States. Tech Rpt. SERDP-97-10, U.S. Army Corps of Engineers.
- Won, I.J., D.A. Keiswetter, D.R. Hanson, E. Novikova, and T.M. Hall. (1997). "GEM-3: A monostatic broadband electromagnetic induction sensor," *Journal of Environmental and Engineering Geophysics* 2(1), pp 53-64.
- Won, I.J., D. Keiswetter, and E. Novikova. 1998. "Electromagnetic induction spectroscopy," *Journal of Environmental and Engineering Geophysics* 3(1), 27-40.

